

UTILITY PATENT APPLICATION TRANSMITTAL

Attorney Docket No. 1075.1013-CC-D3\PIK

First Named Inventor or Application Identifier:

George ISHIKAWA, et al.

Express Mail Label No.

(Only for new nonprovisional applications under 37 CFR 1.53(b))

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

**ADDRESS TO: Assistant Commissioner for Patents
Box Patent Application
Washington, DC 20231**

1. ☒ Fee Transmittal Form
2. ☒ Specification, Claims & Abstract [Total Pages: 145]
3. ☒ Formal Drawings (35 USC 113) [Total Sheets: 35]
4. ☒ Oath or Declaration [Total Pages: 2]
 - a. ☐ Newly executed (original or copy)
 - b. ☒ Copy from a prior application (37 CFR 1.63(d)) (for continuation/divisional with Box 17 completed)
 - i. ☐ **DELETION OF INVENTOR(S)**
Signed statement attached deleting inventor(s) named in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b).
5. ☒ Incorporation by Reference (usable if Box 4b is checked)
The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied under Box 4b, is considered as being part of the disclosure of the accompanying application and is hereby incorporated by reference therein.
6. ☐ Microfiche Computer Program (Appendix)
7. ☐ Nucleotide and/or Amino Acid Sequence Submission (if applicable, all necessary)
 - a. ☐ Computer Readable Copy
 - b. ☐ Paper Copy (identical to computer copy)
 - c. ☐ Statement verifying identity of above copies

ACCOMPANYING APPLICATION PARTS

8. ☐ Assignment Papers (cover sheet & document(s))
9. ☐ 37 CFR 3.73(b) Statement (when there is an assignee) ☐ Power of Attorney
10. ☐ English Translation Document (if applicable)
11. ☒ Information Disclosure Statement (IDS)/PTO-1449 ☒ Copies of IDS Citations
12. ☒ Preliminary Amendment
13. ☒ Return Receipt Postcard (MPEP 503) (Should be specifically itemized)
14. ☐ Small Entity Statement(s) ☐ Statement filed in prior application, status still proper and desired.
15. ☐ Certified Copy of Priority Document(s) (if foreign priority is claimed)
16. ☐ Other:

17. If a CONTINUING APPLICATION, check appropriate box and supply the requisite information:
☐ Continuation ☒ Divisional ☐ Continuation-in-part (CIP) of prior application No: 08/917,292
18. CORRESPONDENCE ADDRESS
 STAAS & HALSEY
 Attn: Paul I. Kravetz -
 700 Eleventh Street, N.W., Suite 500
 Washington, DC 20001

 Telephone: (202) 434-1500
 Facsimile: (202) 434-1501


05/19/98

66793 U.S. PTO

NEW APPLICATION FEE TRANSMITTAL

Attorney Docket No. 1075.1013-CC-D3\PIK

Application Number Div. of 08/917,292

Filing Date May 19, 1998

AMOUNT ENCLOSED \$ 2,694.00

First Named Inventor George ISHIKAWA, et al.

FEE CALCULATION (fees effective 10/01/97)

CLAIMS	(1) FOR	(2) NUMBER FILED	(3) NUMBER EXTRA	(4) RATE	(5) CALCULATIONS
	TOTAL CLAIMS	73 - 20 =	53	X \$ 22.00 =	\$ 1,166.00
	INDEPENDENT CLAIMS	12 - 3 =	9	X \$ 82.00 =	738.00
	MULTIPLE DEPENDENT CLAIMS (any number; if applicable)			+ \$270.00 =	
	BASIC FILING FEE				+ 790.00
	Total of above Calculations =				\$
	Surcharge for late filing fee, Statement or Power of Attorney (\$130.00)				+
	Reduction by 50% for filing by small entity (37 CFR 1.9, 1.27 & 1.28).				-
	TOTAL FILING FEE =				\$ 2,694.00
	Surcharge for filing non-English language application (\$130.00; 37 CFR 1.52(d))				+
	Recordation of Assignment (\$40.00; 37 CFR 1.21(h)(1))				+
	TOTAL FEES DUE =				\$ 2,694.00

METHOD OF PAYMENT

- ☒ Check enclosed as payment.
- ☐ Charge "TOTAL FEES DUE" to the Deposit Account No., below.
- ☐ No payment is enclosed and no charges to the Deposit Account are authorized at this time.

GENERAL AUTHORIZATION

- ☒ If the above-noted "AMOUNT ENCLOSED" is not correct, the Commissioner is hereby authorized to credit any overpayment or charge any additional fees necessary to:

Deposit Account No. 19-3935

Deposit Account Name STAAS & HALSEY

- ☒ The Commissioner is also authorized to credit any overpayments or charge any additional fees required under 37 CFR 1.16 (filing fees) or 37 CFR 1.17 (processing fees) during the prosecution of this application, including any related application(s) claiming benefit hereof pursuant to 35 USC § 120 (e.g., continuations/divisionals/CIPs under 37 CFR 1.53(b) and/or continuations/divisionals/CPAs under 37 CFR 1.53(d)) to maintain pendency hereof or of any such related application.

SUBMITTED BY: STAAS & HALSEY

Typed Name Paul I. Kravetz

Reg. No. 35,230

Signature 

Date

May 19, 1998

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:

George ISHIKAMA, et al.

Serial No.: Div. of 08/917,292

Group Art Unit:

Filed: May 19, 1998

Examiner:

For: OPTICAL WAVELENGTH MULTIPLEX TRANSMISSION METHOD AND
OPTICAL DISPERSION COMPENSATION METHOD

PRELIMINARY AMENDMENT

Honorable Commissioner of Patents and Trademarks
Washington, D.C. 20231

Sir:

This Preliminary Amendment is filed to add new claims for consideration by the Examiner. Therefore, please enter this Preliminary Amendment before examination of the present application.

1075.1013-CC-D3

IN THE CLAIMS

Please **CANCEL** claims 1-90, without prejudice or disclaimer, and before calculating the filing fees for the present application.

Please **ADD** the following NEW claims:

91. (NEW) A repeater comprising:

a first amplifier amplifying an optical signal;
a first dispersion compensator providing dispersion compensation to the amplified optical signal; and
a second amplifier amplifying the optical signal provided with dispersion compensation by the first dispersion compensator.

92. (NEW) A repeater as in claim 91, further comprising:

a second dispersion compensator providing dispersion compensation to the optical signal after being amplified by the first amplifier and before being amplified by the second amplifier.

93. (NEW) A repeater as in claim 92, wherein the first and second dispersion compensators provide different dispersion compensation amounts.

94. (NEW) A repeater as in claim 92, wherein

the first dispersion compensator provides positive dispersion compensation, and

the second dispersion compensator provides negative dispersion

compensation.

95. (NEW) A repeater as in claim 91, wherein the first and second amplifiers are erbium doped optical fiber amplifiers.

96. (NEW) A repeater as in claim 92, wherein the first and second amplifiers are erbium doped fiber amplifiers.

97. (NEW) A repeater as in claim 91, wherein the first dispersion compensator is a dispersion compensation fiber.

98. (NEW) A repeater as in claim 92, wherein the first and second dispersion compensators are dispersion compensation fibers.

99. (NEW) A repeater as in claim 91, wherein the first and second amplifiers have a combined gain so that the optical signal is output from the second amplifier at a power level sufficient to be received by a receiver downstream of the second amplifier.

100. (NEW) A repeater as in claim 92, wherein the first and second amplifiers have a combined gain so that the optical signal is output from the second amplifier at a power level sufficient to be received by a receiver downstream of the second amplifier.

101. (NEW) A repeater as in claim 91, further comprising:

a second dispersion compensator providing dispersion compensation to the optical signal before being amplified by the first amplifier or after being amplified by the second amplifier.

102. (NEW) A repeater as in claim 101, wherein the first and second dispersion compensators provide different dispersion compensation amounts.

103. (NEW) A repeater as in claim 92, further comprising:

a third dispersion compensator providing dispersion compensation to the optical signal after being amplified by the first amplifier and before being amplified by the second amplifier.

104. (NEW) A repeater as in claim 103, wherein the first, second and third dispersion compensators provide different dispersion compensation amounts.

105. (NEW) A repeater comprising:

a plurality of dispersion compensator units optically connected in series, each dispersion compensator unit including
an optical amplifier for amplifying an optical signal,
and

a dispersion compensator providing dispersion

compensation to the optical signal either before or after being amplified by the optical amplifier.

106. (NEW) A repeater as in claim 105, wherein the optical amplifier of each dispersion compensator unit is an erbium doped fiber amplifier.

107. (NEW) A repeater as in claim 105, wherein the dispersion compensator of each dispersion compensator unit is a dispersion compensation fiber.

108. (NEW) A repeater comprising:
an optical amplifier amplifying an optical signal; and
first and second dispersion compensators providing dispersion compensation to the optical signal.

109. (NEW) A repeater as in claim 108, wherein the first and second dispersion compensators both provide dispersion compensation to the optical signal before being amplified by the optical amplifier.

110. (NEW) A repeater as in claim 108, wherein the first and second dispersion compensators both provide dispersion compensation to the optical signal after being amplified by the optical

amplifier.

111. (NEW) A repeater as in claim 108, wherein at least one of the group consisting of the first and second dispersion compensators provides dispersion compensation to the optical signal before being amplified by the optical amplifier.

112. (NEW) A repeater as in claim 108, wherein at least one of the group consisting of the first and second dispersion compensators provides dispersion compensation to the optical signal after being amplified by the optical amplifier.

113. (NEW) A repeater as in claim 108, wherein the first and second dispersion compensators provide different dispersion compensation amounts to the optical signal.

114. (NEW) A repeater as in claim 111, wherein the first and second dispersion compensators provide different dispersion compensation amounts to the optical signal.

115. (NEW) A repeater as in claim 112, wherein the first and second dispersion compensators provide different dispersion compensation amounts to the optical signal.

116. (NEW) A repeater as in claim 108, further comprising:
a third dispersion compensator providing dispersion compensation to the optical signal.

117. (NEW) An apparatus comprising:
a first amplifier amplifying an optical signal;
a first dispersion compensator providing dispersion compensation to the amplified optical signal;
a second amplifier amplifying the optical signal provided with dispersion compensation by the first dispersion compensator; and
an enclosure housing the first and second amplifiers and the dispersion compensator.

118. (NEW) An apparatus as in claim 117, further comprising:
a second dispersion compensator providing dispersion compensation to the optical signal after being amplified by the first amplifier and before being amplified by the second amplifier, the second dispersion compensator being housed in the enclosure.

119. (NEW) An apparatus as in claim 118, wherein the first and second dispersion compensators provide different dispersion compensation amounts.

120. (NEW) An apparatus as in claim 118, wherein
the first dispersion compensator provides positive dispersion
compensation, and
the second dispersion compensator provides negative dispersion
compensation.

121. (NEW) An apparatus as in claim 117, wherein the first
and second amplifiers are erbium doped fiber amplifiers.

122. (NEW) An apparatus as in claim 118, wherein the first
and second amplifiers are erbium doped fiber amplifiers.

123. (NEW) An apparatus as in claim 117, wherein the first
dispersion compensator is a dispersion compensation fiber.

124. (NEW) An apparatus as in claim 118, wherein the first
and second dispersion compensators are dispersion compensation
fibers.

125. (NEW) An apparatus as in claim 117, wherein the first
and second amplifiers have a combined gain so that the optical
signal is output from the second amplifier at a power level
sufficient to be received by a receiver downstream of the second
amplifier.

126. (NEW) An apparatus as in claim 118, wherein the first and second amplifiers have a combined gain so that the optical signal is output from the second amplifier at a power level sufficient to be received by a receiver downstream of the second amplifier.

127. (NEW) An apparatus as in claim 118, further comprising:
a third dispersion compensator providing dispersion compensation to the optical signal after being amplified by the first amplifier and before being amplified by the second amplifier, the third dispersion compensator being housed in the enclosure.

128. (NEW) An apparatus as in claim 127, wherein the first, second and third dispersion compensators provide different dispersion compensation amounts.

129. (NEW) An apparatus comprising:
a plurality of dispersion compensator units optically connected in series, each dispersion compensator unit including
an optical amplifier for amplifying an optical signal,
a dispersion compensator providing dispersion compensation to the optical signal either before or after being amplified by the optical amplifier, and
an enclosure housing the optical amplifier and the

dispersion compensator.

130. (NEW) An apparatus as in claim 129, wherein the optical amplifier of each dispersion compensator unit is an erbium doped fiber amplifier.

131. (NEW) An apparatus as in claim 129, wherein the dispersion compensator of each dispersion compensator unit is a dispersion compensation fiber.

132. (NEW) An apparatus comprising:
an optical amplifier amplifying an optical signal;
first and second dispersion compensators providing dispersion compensation to the optical signal; and
an enclosure housing the optical amplifier and the first and second dispersion compensators.

133. (NEW) An apparatus as in claim 132, wherein the first and second dispersion compensators both provide dispersion compensation to the optical signal before being amplified by the optical amplifier.

134. (NEW) An apparatus as in claim 132, wherein the first and second dispersion compensators both provide dispersion compensation to the optical signal after being amplified by the optical amplifier.

135. (NEW) An apparatus as in claim 132, wherein at least one of the group consisting of the first and second dispersion compensators provides dispersion compensation to the optical signal before being amplified by the optical amplifier.

136. (NEW) An apparatus as in claim 132, wherein at least one of the group consisting of the first and second dispersion compensators provides dispersion compensation to the optical signal after being amplified by the optical amplifier.

137. (NEW) An apparatus as in claim 132, wherein the first and second dispersion compensators provide different dispersion compensation amounts to the optical signal.

138. (NEW) An apparatus as in claim 135, wherein the first and second dispersion compensators provide different dispersion compensation amounts to the optical signal.

a second amplifier positioned downstream of the dispersion compensator, wherein a combined gain of the first and second amplifiers is sufficient to compensate a loss in the dispersion compensator and to produce the optical signal having an output power for transmission downstream of the second amplifier.

143. (NEW) An apparatus as in claim 142, wherein the dispersion compensator is a dispersion compensation fiber.

144. (NEW) An apparatus as in claim 142, wherein the first and second amplifiers are erbium doped fiber amplifiers.

145. (NEW) An apparatus as in claim 143, wherein the first and second amplifiers are erbium doped fiber amplifiers.

146. (NEW) An apparatus as in claim 142, further comprising:
an enclosure which houses the dispersion compensator and the second amplifier.

147. (NEW) A repeater comprising:
a first amplifier amplifying a plurality of optical signals, each having a different wavelength;
a first dispersion compensator providing dispersion compensation to the amplified plurality of optical signals; and
a second amplifier amplifying the plurality of optical signals provided with dispersion compensation by the first dispersion compensator.

148. (NEW) A repeater as in claim 147, wherein the first and second amplifiers are erbium doped optical fiber amplifiers.

149. (NEW) A repeater as in claim 147, wherein the first dispersion compensator is a dispersion compensation fiber.

150. (NEW) A repeater as in claim 147, wherein the first and second amplifiers have a combined gain so that the plurality of optical signals are output from the second amplifier at a power level sufficient to be received by a receiver downstream of the second amplifier.

151. (NEW) An apparatus comprising:

a first amplifier amplifying a plurality of optical signals, each having a different wavelength;

a first dispersion compensator providing dispersion compensation to the amplified plurality of optical signals;

a second amplifier amplifying the plurality of optical signals provided with dispersion compensation by the first dispersion compensator; and

an enclosure housing the first and second amplifiers and the dispersion compensator.

152. (NEW) An apparatus as in claim 151, wherein the first and second amplifiers are erbium doped fiber amplifiers.

153. (NEW) An apparatus as in claim 151, wherein the first dispersion compensator is a dispersion compensation fiber.

154. (NEW) An apparatus as in claim 151, wherein the first and second amplifiers have a combined gain so that the plurality of optical signals are output from the second amplifier at a power level sufficient to be received by a receiver downstream of the second amplifier.

155. (NEW) An apparatus as in claim 152, wherein the first and second amplifiers have a combined gain so that the plurality of optical signals are output from the second amplifier at a power level sufficient to be received by a receiver downstream of the second amplifier.

156. (NEW) An apparatus comprising:

a dispersion compensator providing dispersion compensation to a plurality of optical signals, each having a different wavelength;

a first amplifier positioned upstream of the dispersion compensator; and

a second amplifier positioned downstream of the dispersion compensator, wherein a combined gain of the first and second amplifiers is sufficient to compensate a loss in the dispersion compensator and to produce the plurality of optical signals having

an output power for transmission downstream of the second amplifier.

157. (NEW) An apparatus as in claim 156, wherein the dispersion compensator is a dispersion compensation fiber.

158. (NEW) An apparatus as in claim 156, wherein the first and second amplifiers are erbium doped fiber amplifiers.

159. (NEW) An apparatus as in claim 156, further comprising:
an enclosure which houses the dispersion compensator and the second amplifier.

160. (NEW) An optical transmission system comprising:
a multiplexer wavelength-division-multiplexing a plurality of optical signals, each having a different wavelength, into a multiplexed optical signal, and providing the multiplexed optical signal to an optical fiber;

an apparatus, optically coupled to the optical fiber, including

a first amplifier amplifying the multiplexed optical signal provided to the optical fiber by the multiplexer,

a dispersion compensator providing dispersion compensation to the amplified multiplexed optical signal, and

a second amplifier amplifying the multiplexed optical signal provided with dispersion compensation; and

a demultiplexer wavelength-division-demultiplexing the multiplexed optical signal, as amplified by the second amplifier, into respective optical signals.

161. (NEW) An optical transmission system as in claim 160, wherein a combined gain of the first and second amplifiers is sufficient to compensate a loss in the dispersion compensator and to produce the multiplexed optical signal having an output power for transmission downstream of the apparatus.

162. (NEW) An optical transmission system comprising:
an optical transmitter providing an optical signal to an optical fiber;

an apparatus, optically coupled to the optical fiber, including

a first amplifier amplifying the optical signal provided to the optical fiber by the optical transmitter,

a first dispersion compensator providing dispersion compensation to the amplified optical signal, and

a second amplifier amplifying the optical signal provided with dispersion compensation; and

an optical receiver receiving the optical signal amplified by

2025-08-08 10:00:00

the second amplifier.

163. (NEW) An optical transmission system as in claim 162, wherein the first and second amplifiers have a combined gain so that the optical signal is output from the second amplifier at a power level sufficient to be received by the receiver.

REMARKS

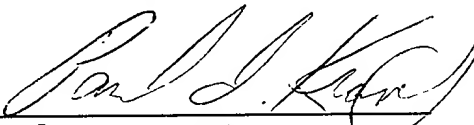
It is respectfully requested that this Preliminary Amendment be entered in the above-referenced application.

In view of the above, it is respectfully submitted that claims 91-163 are currently pending.

If any further fees are required in connection with the filing of this Preliminary Amendment, please charge same to our Deposit Account No. 19-3935.

Respectfully submitted,

STAAS & HALSEY


Paul I. Kravetz
Registration No. 35,230

700 Eleventh Street, N.W.
Suite 500
Washington, D.C. 20001
(202) 434-1500

Date: May 17, 1998

1 TITLE OF THE INVENTION

OPTICAL WAVELENGTH MULTIPLEX TRANSMISSION METHOD
AND OPTICAL DISPERSION COMPENSATION METHOD

5 BACKGROUND OF THE INVENTION

1. Field of the Invention

3446792-00000000
This invention relates to an optical wavelength
multiplex transmission method which uses a band around a
zero dispersion wavelength of an optical fiber and an
10 optical dispersion compensation method for compensating
for waveform degradation by a synergetic effect
(hereinafter referred to as SPM-GVD effect) of self
phase modulation (SPM) and chromatic dispersion (group
velocity dispersion: GVD) which is one of several
15 restrictive factors to the transmission distance and the
transmission rate in a long-haul, very high-speed
optical communication system which employs, for example,
an erbium-doped optical fiber amplifier (Erbium-Doped
Fiber Amplifier, hereinafter referred to as EDFA).

20 2. Description of the Related Art

As a a remarkable increase of the amount of
information proceeds in recent years, a communication
system of a large capacity becomes required, and
investigations for construction of large capacity
25 communication systems are performed hard.

For realization of a large capacity
communication system, realization by an optical

1 communication system is considered most promising. At
present, an optical amplifier multi-repeater system
which employs EDFAs is being put into practical use
together with, for example, a 2.4 Gb/s optical
5 communication system, and in the future, it is forecast
that the amount of information increases progressively
as the information-oriented trend advances. It is
therefore demanded to built up an optical communication
system of an increased capacity corresponding to such
10 increase of the amount of information.

Various methods are available to increase the
capacity of an optical communication system, including a
TDM (time-division multiplexing) method which involves
multiplexing on the time base in order to increase the
15 transmission rate, and a WDM (wavelength-division
multiplexing: wavelength-division multiplexing wherein
the wavelength spacing is comparatively great is called
WDM, and wavelength-division multiplexing which involves
high concentration multiplexing is called FDM
20 (frequency-division multiplexing)) method which involves
multiplexing on the optical wavelength base.

Of the available methods, a multiplexing method
like the TDM method requires an increase of speed of
operation of electronic circuits in a transmitter and a
25 receiver in order to increase the transmission rate. At
present, several tens Gb/s is considered to be the limit
to the speed of operation.

1
5
10
15
20
25

In the WDM (FDM) method which involves wavelength multiplexing on the optical frequency base, however, an available band is restricted from the gain band dependency of an optical amplifier or the wavelength dependency of an optical part. Accordingly, in order to achieve an increase in capacity by multiplexing, the channel spacing must necessarily be decreased to decrease the bandwidth indicated by all channels. Further, in optical transmission of multi-Gigabits, the wavelength of an optical signal must necessarily be set in the proximity of a zero dispersion wavelength of an optical fiber since, otherwise, waveform degradation is caused by chromatic dispersion of the optical fiber.

In an optical communication system to which the WDM (FDM) method is applied in order to achieve such an

1 increase in capacity as described above, however, if the
channel spacing is decreased taking the bandwidth into
consideration and optical signals are set in the
proximity of a zero dispersion wavelength of the optical
5 fiber taking the chromatic dispersion into
consideration, an influence of a non-linear effect of
the optical fiber, particularly of four wave mixing
(hereinafter referred to as FWM), becomes significant,
and there is a subject to be solved in that the
10 transmission may be disabled by crosstalk from another
channel by such FWM. A similar subject resides in
another case wherein wavelength multiplex transmission
must be performed in a band in the proximity of the zero
dispersion wavelength in order to achieve, for example,
15 upgrading of an existing transmission line.

Meanwhile, as a factor of degradation of the
transmission characteristic in the optical amplifier
multi-repeater WDM method which particularly makes use
of a band in the proximity of a zero dispersion
20 wavelength of an optical fiber, crosstalk by FWM
mentioned above is pointed out. The occurrence
efficiency of such FWM depends upon the relationship
between the zero dispersion wavelength of the optical
fiber transmission line and the arrangement of channels.

25 Three characteristics including 1. a zero
dispersion wavelength, 2. a deviation in zero dispersion
wavelength and 3. a dispersion slope (second-order

1 dispersion) are listed as required characteristics for
an optical fiber in the WDM method. Those
characteristics are closely related to five factors
including a. a wavelength multiplexing signal bandwidth,
5 b. a gain bandwidth of the EDFA among various optical
amplifiers. c. a guard band for suppressing FWM to which
the present invention is directed. d. a limitation
bandwidth by an SPM-GVD effect, and e. presence or
absence of an inserted optical dispersion compensator.

10 By the way, as factors which restrict an
increase in distance and an increase in speed of an
optical communication system, there are limitation of
the loss by an optical fiber loss and bandwidth
limitation by chromatic dispersion. The loss limitation
15 has been almost solved by realization of EDFAs, and it
is possible to build up a very long-haul optical
communication system for several thousands km or more.

However, the repeater span in a multi-repeater
optical amplification system is restricted principally
20 by two factors including 1. optical SNR (signal to noise
ratio) degradation caused by accumulation of ASE
(spontaneous emission) from optical amplifier-repeaters,
and 2. waveform degradation by an SPM-GVD effect caused
by a Kerr effect.

25 It is already known that, of the two factors,
the waveform degradation by an SPD-GVD effect can be
compensated for using an optical dispersion compensator

1 having a dispersion value of the opposite positive or
negative sign to that of the optical fiber transmission
line, and the waveform degradation by an SPM-GVD effect
and a dispersion compensation effect can be simulated
5 readily by solving a non-linear Schroedinger equation
using the split-step Fourier method.

An optical dispersion compensator used for the
object described above is required to cope with a
dispersion amount of an optical fiber of a corresponding
10 repeater section and to allow reduction of the number of
steps and of the time necessary to realize an optimum
dispersion compensation amount and reduction of the
cost. Further, the optical dispersion compensation
technique is important not only for a 1.55 μm dispersion
15 shifted fiber (hereinafter referred to as DSF)
transmission line network being laid at present but also
for a long-haul, very high-speed optical communication
system and an optical communication system of the WDM
(FDM) method which make use of an existing 1.3 μm zero
20 dispersion single mode fiber (hereinafter referred to as
SMF) transmission line network.

In a very long-haul optical communication system
for several thousands km or more, it is considered
desirable to use the zero dispersion wavelength λ_0 of
25 the optical fiber transmission line in order to prevent
the dispersion penalty and to use the ordinary
dispersion region (dispersion value $D < 0$) of the

1 optical fiber in order to minimize the non-linear
effect. In order to satisfy the two contradictory
requirements, a countermeasure has been proposed which
makes use of the ordinary dispersion region for the
5 transmission line and employs an optical dispersion
compensator to reduce the apparent dispersion value
equal to zero. The optical dispersion compensation
technique is effective not only for DSF transmission but
also for SMF transmission having a high dispersion value
10 of approximately 18 ps/nm/km.

Various types of optical dispersion compensators .
have been proposed including dispersion compensating
fiber type optical dispersion compensators, transversal
filter type optical dispersion compensators and optical
15 resonator type optical dispersion compensators. At
present, a dispersion compensating fiber is considered
promising from its advantage in that the dispersion
compensation amount can be adjusted readily by varying
the length of the fiber, and dispersion values higher
20 than -100 ps/(nm•km) have been obtained by contriving
the profile of the core.

The zero dispersion wavelength of an actual
optical fiber transmission line presents a deviation in
a longitudinal direction. Further, in an optical
25 communication system on land, since it is difficult to
set the repeater span fixed as in a submarine optical
communication system, the dispersion amount is not

1 always fixed among different repeater sections.
Therefore, ideally an optical dispersion compensator
having an optimum dispersion compensation amount is
inserted into each repeater section after an actual
5 dispersion amount is measured for the repeater section.
However, there is a subject in that such operation
requires a great number of steps of operation, long time
and a high cost to realize optimum optical dispersion
compensators including measurement of dispersion
10 amounts.

SUMMARY OF THE INVENTION

It is an object of the present invention to
provide an optical wavelength multiplex transmission
15 method wherein, where a band in the proximity of a zero
dispersion wavelength of an optical fiber is used,
optical signals are disposed at efficient channel
spacings taking an influence of the band, the chromatic
dispersion and the FWM into consideration to realize an
20 optical communication system of an increased capacity
which is not influenced by crosstalk by FWM.

It is another object of the present invention to
provide an optical wavelength multiplex transmission
method wherein the relationship between characteristics
25 required for an optical fiber, particularly, the zero-
dispersion wavelength and the deviation in zero-
dispersion wavelength, and five specific factors related

1 to the characteristics is made clear to allow
establishment of channel arrangement of and transmission
line designing for signal light by an optical amplifier
multi-repeater WDM method.

5 It is a further object of the present invention
to provide an optical dispersion compensation method by
which waveform degradation by an SPM-GVD effect can be
compensated for readily without designing or producing
optical dispersion compensators suitable for individual
10 transmission lines and dispersion compensation can be
performed effectively even when the optical power is not
so high that SPM (self phase modulation) does not take
place very much but only waveform degradation is caused
by chromatic dispersion (GVD), thereby to reduce the
15 number of steps and the time required to build up an
optical communication system and to achieve reduction of
the cost.

In order to attain the objects described above,
according to an aspect of the present invention, there
20 is provided an optical wavelength multiplex transmission
method for multiplexing signal light waves of a
plurality of channels having different wavelengths and
transmitting the multiplexed signal light using an
optical fiber, wherein a four wave mixing suppressing
25 guard band of a predetermined bandwidth including a
zero-dispersion wavelength of the optical fiber is set,
and the signal light waves of the plurality of channels

1 to be multiplexed are arranged on one of a shorter
wavelength side and a longer wavelength side outside the
guard band.

5 In the optical wavelength multiplex transmission
method, when signal light waves of a plurality of
channels having different wavelengths are multiplexed
and transmitted using an optical fiber, since the signal
light waves of the plurality of channels to be
multiplexed are arranged on one of the shorter
10 wavelength side and the longer wavelength side outside
the four wave mixing suppressing guard band of the
predetermined bandwidth including the zero-dispersion
wavelength of the optical fiber, otherwise possible four
wave mixing is suppressed, and consequently, an
15 influence from another channel by crosstalk is
suppressed.

According to another aspect of the present
invention, there is provided an optical wavelength
multiplex transmission method for multiplexing signal
20 light waves of a plurality of channels having different
wavelengths and transmitting the multiplexed signal
light using an optical fiber, wherein a four wave mixing
suppressing guard band of a predetermined bandwidth
including a zero-dispersion wavelength of the optical
25 fiber is set, and the signal light waves of the
plurality of channels to be multiplexed are arranged on
the opposite sides of a shorter wavelength side and a

1 longer wavelength side outside the guard band.

In the optical wavelength multiplex transmission method, since signal light waves of a plurality of channels to be multiplexed are arranged on the opposite
5 sides of the shorter wavelength side and the longer wavelength side outside the four wave mixing suppressing guard band, otherwise possible four wave mixing is suppressed, and consequently, an influence from another channel by crosstalk is suppressed and efficient
10 utilization of the band can be achieved simultaneously.

The bandwidths of the guard bands may be set in an asymmetrical relationship on the shorter wavelength side and the longer wavelength side with respect to the zero-dispersion wavelength of the optical fiber. In
15 this instance, the channel spacings between adjacent ones of the signal light waves of the plurality of channels may be set different on the shorter wavelength side and the longer wavelength side outside the guard band. Due to the channel spacings thus set, four wave
20 mixing light produced between a signal light wave on the shorter wavelength side and another signal light wave on the longer wavelength side is prevented from coinciding with any of the wavelengths of the signal light waves.

Alternatively, the channel spacings between
25 adjacent ones of the signal light waves of the plurality of channels on each of the shorter wavelength side and the longer wavelength side outside the guard band may be

1 set to an integral number of times a constant. Due to
the channel spacings thus set, in addition to the
advantage that an influence from another channel by
crosstalk is suppressed, the channels on the shorter
5 wavelength side and the longer wavelength side outside
the guard band can be controlled using Fabry-Perot
interferometers of a same characteristic. In this
instance, preferably the channel spacings between the
channels of the signal light waves of the plurality of
10 channels on the opposite sides of the guard band are set
to the integral number of times the constant. Due to
the channel spacings thus set, the channels on the
opposite sides of the shorter wavelength side and the
longer wavelength side outside the guard band can be
15 controlled simultaneously using a single Fabry-Perot
interferometer of a same characteristic. Or else, the
signal light waves of the channels may be arranged such
that the signal light waves of no pair or only one pair
of ones of the channels have dispersion values which
20 have an equal absolute value. The arrangement further
suppresses four wave mixing so that an influence from
another channel by crosstalk can be further suppressed.

With the optical wavelength multiplex
transmission methods described above, the following
25 effects or advantages can be anticipated.

First, an influence of four wave mixing can be
suppressed and the band can be utilized efficiently by

1 arranging signal light waves efficiently, an optical
communication system of a large capacity can be realized
while maintaining high transmission quality.

5 Second, even when a zero-dispersion wavelength
is positioned within a band of an optical amplifier or
within a band of an optical part, signal light waves can
be arranged efficiently and compactly while suppressing
an effect of four wave mixing within the limited band.

10 Third, Since the channel spacings on the
transmission side can be controlled by means of a single
or a pair of Fabry-Perot interferometers and an
interferometer of the same characteristic to that of the
interferometers on the transmission side can be used
also on the reception side, control on the transmission
15 side can be simplified and selective reception is
facilitated.

20 According to a further aspect of the present
invention, there is provided an optical wavelength
multiplex transmission method for multiplexing signal
light waves of a plurality of channels having different
wavelengths and transmitting the multiplexed signal
light using an optical fiber, wherein, taking a zero-
dispersion wavelength λ_0 of the optical fiber and a
zero-dispersion wavelength deviation range $\pm\Delta\lambda_0$ of the
25 optical fiber in its longitudinal direction into
consideration, the signal light waves of the plurality
of channels to be multiplexed are arranged on a shorter

1 wavelength side than a shorter wavelength end $\lambda_0 - \Delta\lambda_0$
of the zero-dispersion wavelength deviation range of the
optical fiber.

5 In the optical wavelength multiplex transmission
method, when signal light waves of a plurality of
channels having different wavelengths are multiplexed
and transmitted using an optical fiber, since the signal
light waves of the plurality of channels to be
10 multiplexed are arranged on the shorter wavelength side
than the shorter wavelength end $\lambda_0 - \Delta\lambda_0$ of the zero-
dispersion wavelength deviation range of the optical
fiber, the zero-dispersion wavelength deviation in the
longitudinal direction of the optical fiber is taken
into consideration and controlled on the shorter
15 wavelength side of the zero-dispersion wavelength.

A four wave mixing suppressing guard band $\Delta\lambda_g$
may be provided on the shorter wavelength side than the
shorter wavelength end $\lambda_0 - \Delta\lambda_0$ of the zero-dispersion
wavelength deviation range of the optical fiber, and the
20 signal light waves of the plurality of channels may be
arranged on a shorter wavelength side than a wavelength
 $\lambda_0 - \Delta\lambda_0 - \Delta\lambda_g$. In this instance, since the signal
light wave of the plurality of channels are arranged on
the shorter wavelength side than the wavelength $\lambda_0 - \Delta\lambda_0$
25 - $\Delta\lambda_g$ taking the four wave mixing suppressing guard band
 $\Delta\lambda_g$ taken into consideration, the zero-dispersion
wavelength deviation in the longitudinal direction of

1 the optical fiber is taken into consideration and
controlled on the shorter wavelength side of the zero-
dispersion wavelength, and simultaneously, an influence
from another channel by crosstalk is suppressed.

5 According to a still further aspect of the
present invention, there is provided an optical
wavelength multiplex transmission method for
multiplexing signal light waves of a plurality of
channels having different wavelengths and transmitting
10 the multiplexed signal light using an optical fiber,
wherein, taking a zero-dispersion wavelength λ_0 of the
optical fiber and a zero-dispersion wavelength deviation
range $\pm\Delta\lambda_0$ of the optical fiber in its longitudinal
direction into consideration, the signal light waves of
15 the plurality of channels to be multiplexed are arranged
on a longer wavelength side than a longer wavelength end
 $\lambda_0 + \Delta\lambda_0$ of the zero-dispersion wavelength deviation
range of the optical fiber.

In the optical wavelength multiplex transmission
20 method, when signal light waves of a plurality of
channels having different wavelengths are multiplexed
and transmitted using an optical fiber, since the signal
light waves of the plurality of channels to be
multiplexed are arranged on the longer wavelength side
25 than the longer wavelength end $\lambda_0 + \Delta\lambda_0$ of the zero-
dispersion wavelength deviation range of the optical
fiber, the zero-dispersion wavelength deviation in the

1 longitudinal direction of the optical fiber is taken
into consideration and controlled on the longer
wavelength side of the zero-dispersion wavelength.

5 A four wave mixing suppressing guard band $\Delta\lambda_g$
may be provided on the longer wavelength side than the
longer wavelength end $\lambda_0 + \Delta\lambda_0$ of the zero-dispersion
wavelength deviation range of the optical fiber, and the
signal light waves of the plurality of channels may be
10 $\lambda_0 + \Delta\lambda_0 + \Delta\lambda_g$. Due to the provision of the four wave
mixing suppressing guard band $\Delta\lambda_g$ and the arrangement of
the signal light waves, the zero-dispersion wavelength
deviation in the longitudinal direction of the optical
fiber is taken into consideration and controlled on the
15 longer wavelength side of the zero-dispersion
wavelength, and simultaneously, an influence of another
channel by crosstalk is suppressed.

The signal light waves of the plurality of
channels may be arranged within a transmissible band
20 defined by an allowable dispersion value determined from
a synergetic effect of self phase modulation and group
velocity dispersion in the optical fiber. Where the
signal light waves are arranged in this manner, they can
be arranged taking wavelength degradation by an SPM-GVD
25 effect into consideration. Further, although SPM does
not take place very much and only waveform degradation
by chromatic dispersion (GVD) occurs when the optical

1 power is not very high, the signal light arrangement can
be performed also taking such waveform degradation into
consideration.

5 The signal light waves of the plurality of
channels may be arranged outside the transmissible band
defined by the allowable dispersion value determined
from the synergetic effect of self phase modulation and
group velocity dispersion in the optical fiber, and the
zero dispersion wavelength λ_0 of the optical fiber may
10 be apparently shifted using an optical dispersion
compensator to apparently arrange the signal light waves
of the plurality of channels into the transmissible
band. Due to the arrangement of the signal light waves
and the shift of the zero dispersion wavelength λ_0 , the
15 signal light waves can be arranged taking waveform
degradation by an SPM-GVD effect into consideration.

The optical wavelength multiplex transmission
method may be constructed such that, taking a dispersion
compensation amount deviation range $\pm\delta\lambda_{DC}$ of the optical
20 dispersion compensator into consideration, a band $\Delta\lambda_{WDM}$
within which the signal light waves of the plurality of
channels are to be arranged is set expanding the same by
the dispersion compensation amount deviation range $\delta\lambda_{DC}$
on the opposite sides of the longer wavelength side and
25 the shorter wavelength side. Due to the band $\Delta\lambda_{WDM}$ thus
set, the signal light waves can be arranged taking the
dispersion compensation amount deviation of the optical

1 dispersion compensator into consideration

The signal light waves of the plurality of channels may be arranged in a gain band of an optical amplifier connected to the optical fiber. Due to the arrangement of the signal light waves, the powers of the signal light waves can be made equal to each other and also the receive characteristics of the signal light waves can be made equal to each other.

A band $\Delta\lambda_{\text{WDM}}$ within which the signal light waves of the plurality of channels are to be arranged may be set expanding the same in accordance with optical wavelength variations of the signal light waves of the plurality of channels. Due to the band $\Delta\lambda_{\text{WDM}}$ thus set, the productivity of light sources of the signal light waves and the variation of each signal light wave by the wavelength control accuracy are taken into consideration.

With the optical wavelength multiplex transmission methods described above, the following effects or advantages can be anticipated.

First, in a wavelength division multiplexing method which makes use of a band in the proximity of the zero-dispersion wavelength λ_0 of the optical fiber, the signal light waves of the individual channels can be arranged without being influenced by four wave mixing, and simultaneously, required characteristics regarding the zero-dispersion wavelength λ_0 for an optical fiber

1 transmission line to be laid can be made clear.
Consequently, channel arrangement of and transmission
line designing for signal light by an optical amplifier
multi-repeater WDM method can be established.

5 Second, the zero-dispersion wavelength deviation
in the longitudinal direction of the optical fiber is
taken into consideration and controlled, and
simultaneously, an influence of four wave mixing is
suppressed so that an influence from another channel by
10 crosstalk is suppressed. Consequently, a high degree of
transmission accuracy can be maintained.

Third, signal light waves can be arranged taking
waveform degradation by an SPM-GVD effect into
consideration, and where the signal light waves of
15 different channels are arranged in the gain bandwidth
 $\Delta\lambda_{EDFA}$ of the EDFA, the powers of the signal light waves
can be made equal to each other and the receive
characteristics of the signal light waves can be made
equal to each other.

20 Fourth, where a signal light band is set
expanding the same in accordance with optical wavelength
variations of the signal light waves of the channels,
the variations of the signal light waves arising from
the productivity and/or the wavelength control accuracy
25 of light sources of the signal light waves such as
semiconductor lasers are taken into consideration, and
where an optical dispersion compensator is employed, by

1 setting the signal light band expanding the same by a
dispersion compensation amount deviation range on the
opposite sides of the shorter wavelength side and the
longer wavelength side, also the dispersion compensation
5 amount deviation of the optical dispersion compensator
is taken into consideration. Consequently, optical
transmission of higher reliability can be achieved.

According to a yet further aspect of the present
invention, there is provided an optical dispersion
10 compensation method for compensating for a dispersion
amount of an optical transmission system which includes
a transmitter, a repeater and a receiver and transmits
signal light from the transmitter to the receiver by way
of the repeater, comprising the steps of preparing in
15 advance two kinds of optical dispersion compensator
units having dispersion amounts having different
positive and negative signs, inserting the two kinds of
optical dispersion compensator units separately into the
optical transmission system, and selecting one of the
20 two kinds of optical dispersion compensator units which
provides a better transmission characteristic to the
optical transmission system and incorporating the
selected optical dispersion compensator unit into the
optical transmission system.

25 In the optical dispersion compensation method,
since two kinds of optical dispersion compensator units
having dispersion amounts having different positive and

1 negative signs are prepared in advance and inserted
separately into an optical transmission system to select
one of the two kinds of optical dispersion compensator
units which provides a better transmission
5 characteristic to the optical transmission system. the
dispersion amount of the optical transmission system can
be compensated for simply when an accurate dispersion
amount cannot be measured but the zero-dispersion
wavelength deviation can be grasped to some degree.

10 According to a yet further aspect of the present
invention, there is provided an optical dispersion
compensation method for compensating for a dispersion
amount of an optical transmission system which includes
a transmitter, a repeater and a receiver and transmits
15 signal light from the transmitter to the receiver by way
of the repeater, comprising the steps of preparing in
advance two kinds of optical dispersion compensator
units having dispersion amounts having different
positive and negative signs, measuring a dispersion
20 amount of the optical transmission system, and selecting
one of the two kinds of optical dispersion compensator
units which has a dispersion amount whose sign is
opposite to that of a measured dispersion amount and
incorporating the selected optical dispersion
25 compensator unit into the optical transmission system.

In the optical dispersion compensation method,
since two kinds of optical dispersion compensator units

1 having dispersion amounts having different positive and
negative signs are prepared in advance and, when the
dispersion amount of an optical transmission system can
be measured, the dispersion amount is measured and then
5 one of the two kinds of optical dispersion compensator
units which has a dispersion value whose sign is
opposite to that of a thus measured dispersion value is
selected. the dispersion amount of the optical
transmission system can be compensated for further
10 reliably.

According to a yet further aspect of the present
invention, there is provided an optical dispersion
compensation method for compensating for a dispersion
amount of an optical transmission system which includes
15 a transmitter, a repeater and a receiver and transmits
signal light from the transmitter to the receiver by way
of the repeater, comprising the steps of preparing in
advance a plurality of kinds of optical dispersion
compensator units having different dispersion amounts
20 having different positive and negative signs.
selectively inserting the plurality of kinds of optical
dispersion compensator units into the optical
transmission system changing the installation number and
the combination of the optical dispersion compensator
25 units, and selecting an installation number and a
combination of the optical dispersion compensator units
from within the plurality of kinds of optical dispersion

1 compensator units which provide a good transmission
characteristic to the optical transmission system and
incorporating the optical dispersion compensator units
of the selected installation number and combination into
5 the optical transmission system.

In the optical dispersion compensation method,
since a plurality of kinds of optical dispersion
compensator units having different dispersion amounts
having different positive and negative signs are
10 prepared in advance and selectively inserted into an
optical transmission system changing the installation
number and the combination of the optical dispersion
compensator units and then an installation number and a
combination of the optical dispersion compensator units
15 which provide a good transmission characteristic to the
optical transmission system are selected from within the
plurality of kinds of optical dispersion compensator
units, the dispersion amount of the optical transmission
system can be compensated for simply and optimally when
20 the zero-dispersion wavelength deviation is unknown or
the zero-dispersion wavelength and the wavelengths of
the signal light waves are displaced by great amounts
from each other.

According to a yet further aspect of the present
25 invention, there is provided an optical dispersion
compensation method for compensating for a dispersion
amount of an optical transmission system which includes

1 a transmitter, a repeater and a receiver and transmits
signal light from the transmitter to the receiver by way
of the repeater, comprising the steps of preparing in
advance a plurality of kinds of optical dispersion
5 compensator units having different dispersion amounts
having different positive and negative signs, measuring
a dispersion amount of the optical transmission system,
and selecting an installation number and a combination
of the optical dispersion compensator units from within
10 the plurality of kinds of optical dispersion compensator
units, with which dispersion values of the signal light
waves fall within a transmissible dispersion value
range, in accordance with a measured dispersion value
and incorporating the optical dispersion compensator
15 units of the selected installation number and
combination into the optical transmission system.

In the optical dispersion compensation method,
since a plurality of kinds of optical dispersion
compensator units having different dispersion amounts
20 having different positive and negative signs are
prepared in advance and, when the dispersion amount of
an optical transmission system can be measured, the
dispersion amount is measured and then an optimum
installation number and an optimum combination of such
25 optical dispersion compensator units are selected in
accordance with a thus measured dispersion amount, the
dispersion amount of the optical transmission system can

1 be compensated for so that it may fall within an
allowable dispersion value range with certainty.

The optical dispersion compensator units may be
additionally incorporated into at least one of the
5 transmitter, the repeater and the receiver of the
optical transmission system to incorporate the optical
dispersion compensator units into the optical
transmission system.

When the optical transmission system performs
10 optical wavelength multiplex transmission to multiplex
and transmit signal light waves of a plurality of
channels having different wavelengths, the signal light
waves may be demultiplexed for each one wave by
wavelength demultiplexing and the optical dispersion
15 compensator units may be provided for the individual
channels of the signal light waves of the wavelengths in
the optical transmission system, or the signal light
waves may be demultiplexed for each plurality of waves
and the optical dispersion compensator units may be
20 provided for the individual channel groups each
including a plurality of signal light waves in the
optical transmission system, or else the optical
dispersion compensator units may be provided for all of
the signal light waves of the plurality of channels in
25 the optical transmission system.

Each of the optical dispersion compensator units
may be additionally provided with an optical amplifier

1 for compensating for an optical loss of the optical
dispersion compensator unit. Due to the additional
provision of the optical amplifier, the optical loss of
each optical dispersion compensator unit can be
5 compensated for. In this instance, a pair of optical
amplifiers may be additionally provided at a preceding
stage and a next stage to each of the optical dispersion
compensator units. Due to the additional provision of
the optical amplifiers, the noise figure (hereinafter
10 referred to as simply NF) of the optical amplifier at
the preceding stage can be set low.

The optical dispersion compensator units may be
constructed as a package wherein they are mounted on a
circuit board so that the optical dispersion compensator
15 units may be replaced or incorporated in units of a
package. Due to the construction of the optical
dispersion compensator units, the dispersion
compensation amount can be varied readily.

According to a yet further aspect of the present
20 invention, there is provided an optical dispersion
compensation method for compensating for a dispersion
amount of an optical transmission system which includes
a transmitter, a repeater and a receiver and transmits
signal light from the transmitter to the receiver by way
25 of the repeater, comprising the steps of incorporating,
in advance into at least one of the transmitter, the
repeater and the receiver of the optical transmission

1 system, a plurality of kinds of optical dispersion
compensator units having different dispersion amounts
having different positive and negative signs in such a
connected condition as to allow switching of a selective
5 combination of the optical dispersion compensator units
by means of switching means, and operating the switching
means to select a suitable combination of the optical
dispersion compensator units from within the plurality
of types of optical dispersion compensator units and
10 incorporating the optical dispersion compensator units
of the selected combination into the optical
transmission system.

In the optical dispersion compensation method,
since a plurality of kinds of optical dispersion
15 compensator units having different dispersion amounts
having different positive and negative signs are
incorporated in advance in at least one of a
transmitter, a repeater and a receiver of an optical
transmission system in such a connected condition as to
20 allow switching of a selective combination of the
optical dispersion compensator units by means of
switching means, a suitable combination of the optical
dispersion compensator units can be selected from within
the plurality of types of optical dispersion compensator
25 units.

The switching means may be operated in response
to a control signal from the outside. In this instance,

1 the optical dispersion compensation method may be
constructed such that the switching means is operated in
response to a control signal from the receiver to switch
the combination of the optical dispersion compensator
5 units while a transmission characteristic of the optical
transmission system is measured simultaneously by the
receiver to determine a combination of the optical
dispersion compensator units which provides an optimum
transmission characteristic to the optical transmission
10 system, and the switching means is operated in response
to another control signal from the receiver to switch
the combination of the optical dispersion compensator
units to the determined combination which provides the
optimum transmission characteristic to the optical
15 transmission system. The switching means may include a
mechanical switch or an optical switch.

With the optical dispersion compensation methods
described above, the following effect or advantage can
be achieved. In particular, waveform deterioration by
20 an SPM-GVD effect and/or the dispersion amount of a
guard band can be compensated for readily without
designing or producing optical dispersion compensators
suitable for individual transmission lines, and
reduction of the number of steps and the time required
25 to build up an optical communication system can be
realized.

Further objects, features and advantages of the

1 present invention will become apparent from the
following detailed description when read in conjunction
with the accompanying drawings in which like parts or
elements are denoted by like reference characters.

5

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagrammatic view illustrating the
arrangement of signal light waves of a plurality of
channels according to an optical wavelength multiplex
10 transmission method of a first preferred embodiment of
the present invention;

FIG. 2 is a block diagram showing the
construction of an optical WDM distribution transmission
system to which the optical wavelength multiplex
15 transmission method of the first embodiment of the
present invention is applied;

FIGS. 3 and 4 are diagrams illustrating
operation of the first embodiment of the present
invention;

20 FIG. 5 is a diagrammatic view illustrating the
arrangement of signal light waves of a plurality of
channels according to an optical wavelength multiplex
transmission method of a second preferred embodiment of
the present invention;

25 FIG. 6 is a similar view but illustrating the
arrangement of signal light waves of a plurality of
channels according to an optical wavelength multiplex

1 transmission method of a third preferred embodiment of
the present invention:

FIG. 7 is a diagram illustrating operation of
the third embodiment of the present invention:

5 FIG. 8 is a diagrammatic view illustrating the
arrangement of signal light waves of a plurality of
channels according to an optical wavelength multiplex
transmission method of a fourth preferred embodiment of
the present invention:

10 FIG. 9 is a similar view but illustrating the
arrangement of signal light waves of a plurality of
channels according to an optical wavelength multiplex
transmission method of a fifth preferred embodiment of
the present invention:

15 FIG. 10 is a similar view but illustrating the
arrangement of signal light waves of a plurality of
channels according to an optical wavelength multiplex
transmission method of a sixth preferred embodiment of
the present invention:

20 FIGS. 11 and 12 are diagrams illustrating
operation of the sixth embodiment of the present
invention:

FIG. 13 is a diagrammatic view illustrating the
arrangement of signal light waves of a plurality of
25 channels according to an optical wavelength multiplex
transmission method of a seventh preferred embodiment of
the present invention:

1 FIG. 14 is a similar view but illustrating a
modification to the arrangement of signal light waves
illustrated in FIG. 13:

5 FIG. 15 is a block diagram showing the
construction of a regenerative repeater system to which
the optical wavelength multiplex transmission method of
the seventh embodiment of the present invention is
applied:

10 FIG. 16 is a graph showing an ASE spectrum of a
gain distribution of an EDFA after connection of EDFAs
at four stages and illustrating a gain band of the EDFA:

 FIG. 17 is a diagram illustrating the
arrangement of an FWM suppressing guard band and
channels:

15 FIG. 18 is a graph illustrating the relationship
between a dispersion value of the channel 1 and
crosstalk:

20 FIG. 19 is a graph illustrating the relationship
between the optical fiber input power and the
regenerative repeater span:

 FIG. 20 is a graph illustrating the signal light
wavelength dependency of the FWM occurrence efficiency:

 FIG. 21 is a graph illustrating the relationship
between the channel spacing and a guard band:

25 FIG. 22 is a graph illustrating the relationship
of the zero-dispersion wavelength and the dispersion
compensation amount to the zero-dispersion wavelength

1 deviation in the seventh embodiment of the present
invention:

FIG. 23 is a diagram illustrating the
arrangement of signal light waves of a plurality of
5 channels according to an optical wavelength multiplex
transmission method of an eighth preferred embodiment of
the present invention:

FIG. 24 is a similar view but illustrating a
modification to the arrangement of signal light waves
10 illustrated in FIG. 23:

FIG. 25 is a graph illustrating the relationship
of the zero-dispersion wavelength and the dispersion
compensation amount to the zero-dispersion wavelength
deviation in the eighth embodiment of the present
15 invention:

FIG. 26 is a block diagram showing an optical
dispersion compensation system to which an optical
dispersion compensation method of a ninth preferred
embodiment of the present invention is applied:

20 FIG. 27 is a block diagram showing an optical
dispersion compensation system to which an optical
dispersion compensation method of a tenth preferred
embodiment of the present invention is applied:

FIG. 28 is a block diagram showing an optical
25 dispersion compensation system to which an optical
dispersion compensation method of an eleventh preferred
embodiment of the present invention is applied:

1 FIG. 29 is a block diagram showing a
modification to the optical dispersion compensation
system shown in FIG. 28;

5 FIG. 30 is a block diagram showing another
modification to the optical dispersion compensation
system shown in FIG. 28;

10 FIG. 31 is a block diagram showing an optical
dispersion compensation system to which an optical
dispersion compensation method of a twelfth preferred
embodiment of the present invention is applied;

 FIG. 32 is a block diagram showing a
modification to the optical dispersion compensation
system shown in FIG. 31;

15 FIG. 33 is a block diagram showing another
modification to the optical dispersion compensation
system shown in FIG. 31;

20 FIG. 34 is a block diagram showing an optical
dispersion compensation system to which an optical
dispersion compensation method of a thirteenth preferred
embodiment of the present invention is applied;

 FIG. 35 is a block diagram showing a
modification to the optical dispersion compensation
system shown in FIG. 34;

25 FIG. 36 is a block diagram showing another
modification to the optical dispersion compensation
system shown in FIG. 34;

 FIG. 37 is a block diagram showing an optical

1 dispersion compensation system to which an optical
dispersion compensation method of a fourteenth preferred
embodiment of the present invention is applied;

FIGS. 38(a) and 38(b) are block diagrams showing
5 a modification to the optical dispersion compensation
system shown in FIG. 37;

FIG. 39 is a block diagram showing another
modification to the optical dispersion compensation
system shown in FIG. 37;

10 FIG. 40 is a schematic illustration showing an
exemplary construction of a package according to the
modified optical dispersion compensation system shown in
FIG. 39;

FIG. 41 is a block diagram showing an optical
15 dispersion compensation system to which an optical
dispersion compensation method of a fifteenth preferred
embodiment of the present invention is applied;

FIG. 42 is a block diagram showing an adaptation
of the optical dispersion compensation system shown in
20 FIG. 41; and

FIG. 43 is a block diagram showing another
adaptation to the optical dispersion compensation system
shown in FIG. 41.

25 DESCRIPTION OF THE PREFERRED EMBODIMENTS

A. First Embodiment

FIGS. 1 to 4 illustrate an optical wavelength

1 multiplex transmission method according to a first
preferred embodiment of the present invention.

First, an optical WDM distribution transmission
system to which the optical wavelength multiplex
5 transmission method of the present embodiment is applied
will be described. Referring to FIG. 2, the optical WDM
distribution transmission system shown includes a
transmission circuit 1 which multiplexes signals from a
plurality of channels into signal light waves having
10 different frequencies or wavelengths in a high density.

The transmission circuit 1 includes a laser
diode (LD-1 to LD-n) 1a provided for each of the
channels CH-1 to CH-n, and a wave combiner 1b for
receiving signal light waves from the laser diodes 1a of
15 the channels and multiplexing the received signal light
waves.

The optical WDM distribution transmission system
further includes an optical fiber 2 for transmitting
multiplexed signal light waves from the transmission
20 circuit 1, a distributor 3 for distributing a signal
from the optical fiber 2 among different channels, and a
reception circuit 4 provided for each of the channels
CH-i ($i = 1$ to n) for receiving signal light of a
frequency or wavelength allocated to the channel. Each
25 of the reception circuits 4 includes an optical filter
4a for extracting and outputting a corresponding signal
from multiplexed signal light, a control circuit 4b for

1 controlling the optical filter 4a, and a detector 4c for
detecting signal light from the optical filter 4a.

By the way, FWM as a non-linear effect of the
optical fiber 2 is a phenomenon which is produced by
5 optical frequency mixing between different signal light
waves having different frequencies or wavelengths from
each other when the signal light waves are multiplexed
and inputted to the optical fiber 2 using a band in the
proximity of the zero-dispersion wavelength of the
10 optical fiber 2, and makes a factor of crosstalk from
another channel and degrades the signal transmission
characteristic.

The FWM which is a non-linear effect of the
optical fiber 2 has a most significant influence upon
15 optical WDM (FDM) transmission which employs a band in
the proximity of the zero-dispersion wavelength of the
optical fiber 2. In order to give a more detailed
description of the FWM, a system design which must be
performed taking an influence of the FWM into
20 consideration, particularly, the channel spacing, the
channel arrangement and the input power, will be
described below.

For example, when signal light waves of
frequencies f_1 to f_n (wavelengths λ_1 to λ_n) are
25 inputted, a fourth light wave of a frequency f_{ijk}
(wavelength λ_{ijk} ; $i \neq k$, $j \neq k$) is generated from
arbitrary three waves f_i , f_j and f_k (wavelengths λ_i , λ_j

1 and λ_k) of the signal light waves in accordance with the
 third-order non-linear susceptibility χ_{1111} of the
 optical fiber 2, and makes an FWM wave. The FWM wave of
 the frequency f_{ijk} (frequency λ_{ijk}) appears at the
 5 position of an optical frequency which satisfies the
 following equation (1), and when the number of channels
 is great with an equal frequency spacing, several FWM
 waves appear at the positions of the frequencies f_{ijk}
 (wavelengths λ_{ijk}) according to combinations of i , j and
 10 k and are superimposed on signal light waves.
 Consequently, the crosstalk is further degraded.

$$f_{ijk} = f_i + f_j - f_k \quad (\lambda_{ijk} = \lambda_i + \lambda_j - \lambda_k) \quad (1)$$

Meanwhile, the frequency f_{ijk} (wavelength λ_{ijk})
 exhibits a high occurrence efficiency in the proximity
 15 of the zero-dispersion wavelength, and the efficiency is
 varied by the phase relationship among the frequencies
 f_i , f_j , f_k and f_{ijk} (wavelengths λ_i , λ_j , λ_k and λ_{ijk}),
 or the efficiency becomes higher as the phase
 inconsistency amount $\Delta\beta$, which will be hereinafter
 20 described, increases.

Generally, where polarization conditions of
 three signal channels coincide with each other, the
 optical power P_{ijk} of an FWM wave is given by the
 following equation (2):

$$P_{ijk} = \eta_{ijk} \cdot \{(1.024\pi^6 \cdot \chi_{1111}^2 \cdot d^2) / n^4 \cdot \lambda^2 \cdot c^2\} \\ \cdot (L_{eff} / A_{eff})^2 \cdot P_i \cdot P_j \cdot P_k \cdot \exp(-\alpha L) \quad (2)$$

where η_{ijk} is the occurrence efficiency of the frequency

1 χ_{ijk} (wavelength λ_{ijk}). χ_{1111} is the third-order non-
linear susceptibility, d is the degeneracy coefficient
($d = 6$ when $i \neq j \neq k$, and $d = 3$ when $i = j \neq k$). n is
the refraction index of the core, λ is the signal
5 wavelength, c is the velocity of light, L_{eff} is the
effective optical fiber length given by the equation (3)
given below, A_{eff} is the effective core area ($= \pi W^2$, W
is the mode field diameter), α is the attenuation
coefficient of the optical fiber, and P_i , P_j and P_k are
10 the input powers of signal light waves of the
frequencies f_i , f_j and f_k (wavelengths λ_i , λ_j and λ_k),
respectively.

$$L_{eff} = \{1 - \exp(-\alpha L)\} / \alpha \quad (3)$$

where the occurrence efficiency η_{ijk} ($= \eta$) is given by
15 the following equation (4):

$$\eta = \alpha^2 \cdot [1 + 4 \exp(-\alpha L) \cdot \sin^2(\Delta\beta L/2)] / \{1 - \exp(-\alpha L)\}^2 / (\alpha^2 + \Delta\beta^2) \quad (4)$$

where L is the optical fiber length, and $\Delta\beta$ is the phase
inconsistency amount. Further, if it is assumed that
20 the dispersion slope $dD/d\lambda$ of the optical fiber, 2 is
fixed with respect to the wavelength, the phase
inconsistency amount $\Delta\beta$ is given by the equation (5) or
(6) below:

- a. In the case of $f_i \neq f_j \neq f_k$ ($\lambda_i \neq \lambda_j \neq \lambda_k$):
- 25
$$\Delta\beta = (\pi\lambda^4/3c^2) \cdot (dD/d\lambda) \cdot \{(f_i + f_j - f_k - f_0)^3 - (f_i - f_0)^3 - (f_j - f_0)^3 + (f_k - f_0)^3\} \quad (5)$$
- b. In the case of $f_i = f_j \neq f_k$ ($\lambda_i = \lambda_j \neq \lambda_k$):

1
$$\Delta\beta = (\pi\lambda^4/c^2) \cdot (dD/d\lambda) \cdot 2 \cdot (f_i - f_0) \cdot (f_i - f_k)^2 \quad (6)$$

where D is the chromatic dispersion of the optical fiber. $dD/d\lambda$ is the chromatic dispersion of the second order of the optical fiber. and f_0 is the zero-dispersion optical frequency. It is to be noted that the equations (5) and (6) stand also where the frequencies f_i , f_j , f_k and f_0 are replaced by the wavelengths λ_i , λ_j , λ_k and λ_0 , respectively.

Where a plurality of channels are involved, combinations of i, j and k of FWM waves which appear at the positions of the frequency f_{ijk} (wavelength λ_{ijk}) are calculated, and optical powers P_{ijk} are individually calculated for them. Then, the sum total of the optical powers P_{ijk} makes an optical power of the FWM wave produced at the position of the frequency f_{ijk} (wavelength λ_{ijk}). Using the sum total of the optical powers, a crosstalk amount CR is calculated in accordance with the following equation (7):

20
$$CR = 10 \cdot \log\{(\text{sum total of all FWM optical powers appearing at positions of } f_{ijk}) / (\text{signal optical power at positions of } f_{ijk})\}$$

(7)

The influence of FWM can be estimated using the equations (2) and (4) to (7), which allows designing of values of parameters of the system such as a channel spacing, a channel arrangement and an input power. In the description of action and effects of the first to

1 sixth embodiments of the invention given below. an
estimated influence of FWM (refer to FIG. 3, 4, 7, 11 or
12) obtained in accordance with the equations given
hereinabove will be used suitably.

5 As described hereinabove, in order to prevent
waveform deterioration by dispersion of the optical
fiber 2, it is necessary to make use of a band in the
proximity of the zero-dispersion wavelength of the
optical fiber and also to assure a channel spacing and
10 a signal channel arrangement taking an influence of FWM,
which appears significantly when the band is used for
multiplexing, into consideration. To this end, in the
optical wavelength multiplex transmission method
according to the first embodiment of the present
15 invention, signal light waves of different channels are
arranged, for example, as illustrated in FIG. 1.

According to such a channel arrangement as
illustrated in FIG. 1, an FWM suppressing guard band 5
of a fixed width ranging from a zero-dispersion
20 wavelength λ_0 is provided, and signal light waves are
disposed on the longer wavelength side 6 than the zero-
dispersion wavelength λ_0 outside the guard band 5.

Due to the construction described above, in the
optical wavelength multiplex transmission system to
25 which the optical wavelength multiplex transmission
method according to the first embodiment of the present
invention is applied, signals from the different

1 channels are multiplexed in a high density as signal
light waves of different frequencies or wavelengths from
one another by the transmission circuit 1 and
transmitted by way of the optical fiber 2.

5 The signal light waves transmitted by way of the
optical fiber 2 are demultiplexed by the distributor 3
and inputted to the reception circuits 4 of the
corresponding channels and detected as signal light
waves of the frequencies or wavelengths corresponding to
10 the input channels.

In this instance, where the system is
constructed, for example, such that the number of
channels of the transmission circuit 1 is 16 ($n = 16$);
the channel spacing is 150 GHz; the length L of the
15 optical fiber 2 is 90 km; and the optical input power P
of each channel is +3 dBm, the results of calculation of
crosstalk amounts of the channels are such as
illustrated in FIG. 3. The parameters used for the
calculation are $\chi_{1111} = 5.0 \times 10^{-15} \text{ cm}^3/\text{erg(esu)}$, $A_{eff} =$
20 $4.6 \times 10^{-11} \text{ m}^2$, $\alpha = 5.2958 \times 10^{-5} \text{ m}^{-1}$ (0.23 dB/km), and
 $dD/d\lambda = 0.065 \text{ ps}/(\text{km} \cdot \text{nm}^2)$.

In FIG. 3, such a representation as "0.0
ps/nm/km" indicates a value of dispersion at the channel
1 CH1. As the channel number (CH No.) increases, the
25 dispersion value increases in accordance with the
dispersion slope $dD/d\lambda$. From the result illustrated in
FIG. 3, the crosstalk amounts at the channels CH2, CH3

1 and CH4 exhibit comparatively high values

Results of calculation performed paying
attention to the channels CH2, CH3 and CH4 are
illustrated in FIG. 4. As seen from FIG. 4, in order to
5 suppress the crosstalk amount, for example, below 30 dB,
the dispersion value of the channel CH1 should be 0.64
ps/nm/km or more, and where, for example, $dD/d\lambda = 0.065$
ps/(km·nm²), the channel CH1 should be displaced
approximately 10 nm from the zero-dispersion wavelength
10 λ_0 . Accordingly, the guard band 5 should have a width
of 10 nm.

In this manner, according to the optical
wavelength multiplex transmission method of the first
embodiment, by arranging signal light waves of different
15 channels from the zero-dispersion wavelength λ_0 of the
optical fiber 2 with the guard band 5 interposed
therebetween, an influence of FWM can be suppressed and
an influence from another channel by crosstalk can be
suppressed. Further, since the band can be utilized
20 efficiently, an optical communication system of an
increased capacity can be realized while maintaining a
high degree of transmission accuracy.

It is to be noted that, while, in the present
embodiment, signal light waves are arranged on the
25 longer wavelength side 6 with respect to the zero-
dispersion wavelength λ_0 , they may alternatively be
arranged on a shorter wavelength side 7 with respect to

1 the zero-dispersion wavelength λ_0 with the guard band 5
interposed therebetween.

B Second Embodiment

Subsequently, an optical wavelength multiplex
5 transmission method according to a second preferred
embodiment of the present invention will be described.
FIG. 5 illustrates an arrangement of signal light waves
of a plurality of channels of the optical wavelength
multiplex transmission method. It is to be noted that
10 also the optical wavelength multiplex transmission
method of the second embodiment is applied to a system
similar to the optical WDM (FDM) distribution
transmission system described hereinabove with reference
to FIG. 2, and overlapping description of the same will
15 be omitted herein to avoid redundancy.

In the optical wavelength multiplex transmission
method according to the present embodiment, a pair of
FWM suppressing guard bands 5 are provided on the
opposite sides of the zero-dispersion wavelength λ_0 , and
20 signal light waves of different channels are arranged on
the shorter wavelength side 7 and the longer wavelength
side 6 outside the guard bands 5.

Due to the channel arrangement described above,
with the optical wavelength multiplex transmission
25 method of the second embodiment, even if the zero-
dispersion wavelength λ_0 is positioned within a band of
an optical amplifier or of an optical part, signal light

1 waves can be arranged efficiently and compactly while
suppressing an effect of FWM in the limited band to
suppress an influence from another channel by crosstalk,
and accordingly, there is an advantage in that an
5 increase of the capacity of the system can be realized
while maintaining a high degree of transmission
accuracy.

C. Third Embodiment

Subsequently, an optical wavelength multiplex
10 transmission method according to a third preferred
embodiment of the present invention will be described.
FIG. 6 illustrates an arrangement of signal light waves
of a plurality of channels of the optical wavelength
multiplex transmission method, and FIG. 7 illustrates
15 operation according to the optical wavelength multiplex
transmission method. It is to be noted that also the
optical wavelength multiplex transmission method of the
third embodiment is applied to a system similar to the
optical WDM (FDM) distribution transmission system
20 described hereinabove with reference to FIG. 2, and
overlapping description of the same will be omitted
herein to avoid redundancy.

According to the optical wavelength multiplex
transmission method of the third embodiment, as shown in
25 FIG. 6, a pair of FWM suppressing guard bands 5 are
provided in an asymmetrical relationship on the shorter
wavelength side 7 and the longer wavelength side 6 with

1 respect to the zero-dispersion wavelength λ_0 , and signal
light waves to be multiplexed are arranged such that the
channel spacing thereof is set different between the
shorter wave side 7 (Δf) and the longer wavelength side
5 6 ($\Delta f'$).

Since the channel spacing is set different
between the shorter and longer wavelength sides than the
guard bands 5, it can be prevented that the position at
which FWM light appears between signal light on the
10 shorter wavelength side and signal light on the longer
wavelength side than the guard bands coincides with some
signal light wavelength, and consequently, an influence
from another channel by crosstalk is suppressed. Here,
the width by which the band in which FWM light may
15 appear is displaced from the band of the signal light is
desirably set within a range within which the width can
be suppressed by the optical filter 4a on the reception
side.

Where the channel spacing is made different
20 between the left and the right such that it is set, for
example, as shown in FIG 7, to 200 GHz on the shorter
wavelength side 7 and to 150 GHz on the longer
wavelength side 6 and the width of the guard band 5 is
set to 1.6 nm on the shorter wavelength side 7 and to 4
25 nm on the longer wavelength side 6, FWM light is
produced between different channels, but production of
FWM light is reduced within the bands of signal light

1 and also the crosstalk amount is reduced.

In this manner, also with the optical wavelength
multiplex transmission method of the third embodiment,
since signal light waves of different channels are
5 arranged on the opposite sides of the zero-dispersion
wavelength λ_0 in a spaced relationship from the zero-
dispersion wavelength λ_0 with the guard bands 5
interposed between them, an influence of FWM can be
suppressed and an influence from another channel by
10 crosstalk can be suppressed. Further, since the band
can be utilized efficiently, there is an advantage in
that an increase of the capacity of the system can be
realized while maintaining a high degree of transmission
accuracy.

15 D. Fourth Embodiment

Subsequently, an optical wavelength multiplex
transmission method according to a fourth preferred
embodiment of the present invention will be described.
FIG. 8 illustrates an arrangement of signal light waves
20 of a plurality of channels of the optical wavelength
multiplex transmission method. It is to be noted that
also the optical wavelength multiplex transmission
method of the fourth embodiment is applied to a system
similar to the optical WDM (FDM) distribution
25 transmission system described hereinabove with reference
to FIG. 2, and overlapping description of the same will
be omitted herein to avoid redundancy.

1 In the optical wavelength multiplex transmission
method of the fourth embodiment, the channel spacings on
the shorter wavelength side 7 and the longer wavelength
side 6 are set individually to a constant multiplied by
5 different integral numbers as seen from FIG. 8.

 If, for example, the channel spacing Δf is $\Delta f =$
 $A \cdot X$, then the channel spacing between a channel $n+4$ and
another channel $n+5$ is set to $\Delta f' = B \cdot X$, and the channel
spacing between a channel $n+m-1$ and another channel $n+m$
10 is set to $\Delta f'' = C \cdot X$. Here, X is the constant, and A , B
and C are the integral numbers.

 Further, as seen from FIG. 8, also in the
present embodiment, the FWM suppression guard bands 5
are arranged asymmetrically on the shorter wavelength
15 side 7 and the longer wavelength side 6 with respect to
the zero-dispersion wavelength λ_0 .

 In the transmission circuit 1 shown in FIG. 2,
it is required to stabilize the wavelengths of the laser
diodes 1a in a desired channel arrangement and at a
20 desired channel spacing, while in the reception circuit
4, it is required to select and extract a channel. The
channel arrangement and the channel spacing required in
order to suppress such an influence of FWM as described
above are desired to be easy to control by the
25 transmission circuit 1 and easy to extract by the
reception circuit 4.

 Generally, control of the channel spacing is

1 performed making use of a periodic characteristic of an
optical interferometer. When it is tried, for example,
to perform control of the channel spacing using Fabry-
Perot interferometers, if the desired channel spacing is
5 equal to the distance between transmission peaks of the
Fabry-Perot interferometers or equal to an integral
number of times the distance between such transmission
peaks, then if the wavelengths of the individual laser
diodes 1a are stabilized at the positions of the
10 transmission peaks using one of the Fabry-Perot
interferometers as a reference, control of all of the
channels can be realized simply. However, where the
channels are arranged at different spacings, control is
complicated.

15 From such point of view, by setting the channel
spacings on the shorter wavelength side 7 and the longer
wavelength side 6 than the zero-dispersion wavelength λ_0
to integral numbers of times a constant (distance of one
period of transmission peaks of optical interferometers
20 or an integral number of times the distance), channels
on the shorter wavelength side 7 and the longer
wavelength side 6 can be controlled by one or two Fabry-
Perot interferometers of the same characteristic. This
similarly applies to the reception circuit 4. In
25 particular, by setting the channel spacings to integral
numbers of times a constant, an interferometer of the
same characteristic can be used.

1 In this manner, with the optical wavelength
multiplex transmission method of the fourth embodiment,
since the channel spacings on the transmission side can
be controlled by means of a single or two Fabry-Perot
5 interferometers, there is an advantage in that the
control on the transmission side can be simplified.

 This also applies to the reception side. In
particular, by setting the channel spacings to integral
numbers of times a constant, an interferometer having
10 the same characteristic as that of the interferometers
on the transmission side can be used. Consequently,
there is an advantage in that selective reception is
facilitated and the apparatus can be simplified.

 It is to be noted that, in the present
15 embodiment, the channel spacing between adjacent
channels of signal light waves of a plurality of
channels can be set such that it may be different on the
shorter wavelength side 7 and the longer wavelength side
6 outside the guard bands 5.

20 E. Fifth Embodiment

 Subsequently, an optical wavelength multiplex
transmission method according to a fifth preferred
embodiment of the present invention will be described.
FIG. 9 illustrates an arrangement of signal light waves
25 of a plurality of channels of the optical wavelength
multiplex transmission method. It is to be noted that
also the optical wavelength multiplex transmission

1 method of the fifth embodiment is applied to a system
similar to the optical WDM (FDM) distribution
transmission system described hereinabove with reference
to FIG. 2, and overlapping description of the same will
5 be omitted herein to avoid redundancy.

In the optical wavelength multiplex transmission
method of the fifth embodiment, the frequencies or
wavelengths of signal light waves of different channels
are set such that the spacings between the signal light
10 waves of the channels arranged on the opposite sides of
the FWM suppression guard bands 5 may satisfy the
relationship wherein the signal light waves are spaced
from each other by spacings equal to integral numbers of
times a constant on the opposite sides of the guard
15 bands 5.

In particular, where the optical frequency of
the channel CH_i is represented by f , the optical
frequency of an arbitrary channel j is set so as to
satisfy $f \pm A \cdot X$, where A is an integral number and X is
20 a constant.

Due to the channel arrangement described above,
with the optical wavelength multiplex transmission
method of the fifth embodiment, the channel spacings on
the opposite sides of the guard bands 5 can be set to
25 integral numbers of times a constant (distance of one
period of transmission peaks of an optical
interferometer or an integral number of times the

1 distance). and consequently, control of the channel
spacings on the transmission side can be realized only
with a single optical interferometer. Further, since it
is only required to use an interferometer of the same
5 characteristic on the reception side, there is an
advantage in that selective reception is facilitated and
the apparatus is simplified.

F. Sixth Embodiment

Subsequently, an optical wavelength multiplex
10 transmission method according to a sixth preferred
embodiment of the present invention will be described.
FIG. 10 illustrates an arrangement of signal light waves
of a plurality of channels of the optical wavelength
multiplex transmission method, and FIGS. 11 and 12
15 illustrate operation of the same. It is to be noted
that also the optical wavelength multiplex transmission
method of the sixth embodiment is applied to a system
similar to the optical WDM (FDM) distribution
transmission system described hereinabove with reference
20 to FIG. 2, and overlapping description of the same will
be omitted herein to avoid redundancy.

In the optical wavelength multiplex transmission
method of the sixth embodiment, different channels are
arranged such that two or more channels may not overlap
25 with each other, that is, one pair of channels or less
may have an equal absolute value of a dispersion value
when the channel arrangement is folded on itself at the

1 zero-dispersion wavelength λ_0 as viewed on the optical
frequency (optical wavelength) axis as seen in FIG. 10.
In the arrangement shown in FIG. 10, only one pair of
channels CH3 and CH8 overlap with each other.

5 Where, for example, the channel number of the
transmission circuit 1 is 16; the channel spacings are
150 GHz, 200 GHz and 250 GHz; the length L of the
optical fiber 2 is 90 km; and the optical input power P
per one channel is 0 dBm, results of calculation of
10 crosstalk of different channels are such as illustrated
in FIG. 11, and in the case of another system wherein
the channel number of the transmission circuit 1 is 16;
the channel spacings are 150 GHz, 200 GHz and 300 GHz;
the length L of the optical fiber 2 is 90 km; and the
15 optical input power P per one channel is 0 dBm, results
of calculation of crosstalk of different channels are
such as illustrated in FIG. 12. As seen from FIG. 11 or
12, all of the channels exhibit good values of cross
talk around -30 dB.

20 While an influence of crosstalk at the channel
CH2, CH5, CH11 or CH15 can be seen in FIG. 7 which
illustrates operation of the third embodiment, if the
channel arrangement illustrated in FIG. 7 is folded on
itself at the zero-dispersion wavelength λ_0 , the
25 channels CH2 and CH15 overlap with each other and the
channels CH5 and CH11 overlap with each other. In other
words, the two pairs of channels have equal absolute

1 values of dispersion values. In contrast, in the
present embodiment, by setting the channel arrangement
so that only one pair of channels may be allowed to have
an equal absolute value of a dispersion value as seen in
5 FIGS. 11 and 12, crosstalk exhibits good values around
approximately -30 dB with all of the channels as
described hereinabove.

Where two or more pairs of channels have equal
absolute values of dispersion values on the opposite
10 sides of the zero-dispersion wavelength λ_0 , as can be
seen also from the equation (5) given hereinabove, the
phase mismatch amount $\Delta\beta$ exhibits the value 0 with a
combination of three channels within two pairs of
channels, and FWM light appears in a high efficiency at
15 the position of the remaining one channel. After all,
FWM light appears at the optical frequency positions of
all of the four channels of the two pairs and degrades
the crosstalk. Accordingly, the channels are set such
that less than two pairs of channels may have an equal
20 absolute value of a dispersion value.

In this manner, with the optical wavelength
multiplex transmission method of the sixth embodiment,
since less than two pairs of channels have an equal
value of a dispersion value on the opposite sides of the
25 zero-dispersion wavelength λ_0 , production of FWM light
can be suppressed, and an influence from another channel
by crosstalk can be suppressed with certainty. Further,

1 since a band can be utilized efficiently similarly as in
the first to fifth embodiments described above, there is
an advantage in that an increase of the capacity of the
system can be realized while maintaining a high degree
5 of transmission accuracy.

It is to be noted that, while, in the first to
sixth embodiments described above, the channel spacing
is set in terms of a frequency, it may alternatively be
set in terms of a wavelength, and also in this instance,
10 similar advantages to those of the embodiments described
above can be achieved.

G. Seventh Embodiment

In order to suppress and eliminate crosstalk by
FWM between signal light waves in an optical
15 transmission system based on the WDM method which
employs a band around the zero-dispersion wavelength of
an optical fiber (in a seventh preferred embodiment of
the present invention, such an optical amplifier multi-
repeater system (regenerative repeater system) as
20 described hereinbelow with reference to FIG. 15), it is
required to separate a signal light band and the zero-
dispersion wavelength of the optical fiber from each
other as described hereinabove. The channel arrangement
then depends principally upon a guard band for
25 suppression of FWM (guard band or bands 5 described in
the first to sixth embodiments), a limiting band by an
SPD-GVD effect and a gain band of an EDFA. Meanwhile,

1 the zero-dispersion wavelength of an actual optical
fiber exhibits a deviation in its longitudinal
direction. and it is very important for designing of a
system to control the zero-dispersion wavelength and the
5 deviation of the zero-dispersion wavelength. Further,
the apparent zero-dispersion wavelength can be shifted
by employment of an optical dispersion compensator,
which provides an advantage to allow the deviation of
the zero-dispersion wavelength.

10 In the seventh and eighth embodiments described
below, a channel arrangement method according to the WDM
method when the factors described above are taken into
consideration will be described. Conversely speaking,
this can be regarded as a defining method between the
15 zero-dispersion wavelength of an optical fiber and the
deviation of the zero-dispersion wavelength in a
situation wherein the number of channels and the channel
spacing are decided.

In the following description, a limiting band by
20 a. a wavelength multiplex signal band, b. a gain band of
an EDFA, c. a guard band for suppression of FWM and d.
an SPM-GVD effect, which are factors to limit the signal
light band, will be described first, and then the
relationship between a channel arrangement and
25 characteristics required for an optical fiber will be
described taking presence or absence of an inserted
optical dispersion compensator into consideration.

1 •Limiting Factors

a. Wavelength Multiplex Signal Band

Where signal light of n waves is arranged at an equal wavelength spacing (channel spacing) $\Delta\lambda_s$, a wavelength multiplex signal light band $\Delta\lambda_{WDM}$ is given by $\Delta\lambda_s \times (n - 1)$. It is to be noted that, in the case of an equal wavelength spacing arrangement, FWM light in the signal light band is liable to become high while wavelength stabilization is facilitated as described hereinabove in the fourth and fifth embodiments.

b. EDFA Gain Band

In the case of optical transmission of the WDM method, in order to make the reception characteristic equal among different waves, the signal light power must be made equal among the different waves, and to this end, a frequency band in which the gain of the EDFA exhibits a flat characteristic must be used. For example, in FIG. 16, an example of an ASE spectrum after EDFAs are connected at four stages (the ASE spectrum distribution is substantially equal to the gain; distribution of an EDFA) is illustrated, and in the EDFA technique at present, the range of 1.550 to 1.560 nm is a frequency band in which the gain is flat. Consequently, it is desirable to arrange signal light of all channels within the bandwidth ($\Delta\lambda_{EDFA} = 10$ nm).

It is to be noted that, as another frequency band than that described above, a frequency band in the

1 proximity of 1.535 nm at which the gain is equal may be
used. It is to be noted that, as factors to decide the
channel spacing then, there are a wavelength selective
filter characteristic, wavelength stability of a
5 semiconductor laser and so forth. Further, as means for
expanding the gain bandwidth $\Delta\lambda_{EDFA}$ of the EDFA,
optimization of an EDFA operation point, optimization of
composition of the EDF, insertion of an optical notch
filter and so forth may be available.

10 c. Guard Band for FWM Suppression

As described also in the first embodiment, in
optical WDM (FDM) transmission which employs a band in
the proximity of the zero-dispersion wavelength of an
optical fiber, it is required to set a channel spacing,
15 a channel arrangement and an input power taking an
influence of FWM into consideration. For example, when
signal light waves of, for example, wavelengths λ_1 to λ_n
are inputted, a fourth light wave (FWM wave) of the
wavelength λ_{ijk} ($i \neq k$, $j \neq k$) is produced from
20 arbitrary three λ_i , λ_j and λ_k of the input signal light
waves by a third-order non-linear susceptibility $\chi^{(3)}$
of the optical fiber.

The wavelength λ_{ijk} satisfies the relationship
of the equation (1) given hereinabove and causes
25 crosstalk and degrades the transmission characteristic
when signal light is present at the position.
Particularly where the channel spacings are equal and

1 the number of channels is great, a plurality of FWM
waves are overlapped at the positions of wavelengths
 λ_{ijk} by combinations of i , j and k , resulting in
increase of the crosstalk amount. Further, the
5 production efficiency η_{ijk} of the wavelength λ_{ijk} varies
depending upon the phase relationship among the
wavelengths λ_i , λ_j , λ_k and λ_{ijk} and indicates a high
value in the proximity of the zero-dispersion wavelength
 λ_0 of the optical fiber.

10 Generally, when the polarization conditions of
three signal light waves and the phases of the three
signal light waves at the input terminal of an optical
fiber, the FWM optical powers P_{ijk} and the production
efficiencies η_{ijk} are given by the equations (2) and (3)
15 and the equations (4) to (6) given hereinabove.

An example of calculation of crosstalk amounts
(refer to the equation (7) given hereinabove) of
different channels where 16 signal light waves are
arranged at an equal distance of the wavelength spacing
20 $\Delta\lambda_s = 1.2$ nm as shown, for example, in FIG. 17 and when
the dispersion value $D_{0\omega_1}$ of the channel 1 is varied is
illustrated in FIG. 18. Parameters used for the
calculation are: $\lambda = 1.55$ μm , $\chi_{1111} = 5.0 \times 10^{-15}$ esu,
 $A_{eff} = 4.6 \times 10^{-11}$ m^2 , $\alpha = 5.3 \times 10^{-5}$ m^{-1} (0.23 dB/km),
25 $dD/d\lambda = 0.065$ ps/(km \cdot nm 2), $L = 90$ km, and $P_i = 0$ dBm/ch.

As seen from FIG. 18, the number of combinations
of FWM light waves overlapped with different channels

1 exhibits its maximum value with the channel 7 or 8 at
the center. However, since the dispersion values at the
different channels are different, the crosstalk amount
exhibits a maximum level with the channels 2 to 4 (this
5 is a similar result to that described hereinabove with
reference to FIG. 3 in connection with the first
embodiment). Where the required crosstalk amount is -30
dB, the dispersion value $D_{0.1}$ of the channel 1 must
necessarily be set to 0.25 ps/(km·nm). In other words,
10 the wavelength spacing between the zero-dispersion
wavelength λ_0 and the wavelength λ_1 of the channel 1
must necessarily be set to 3.8 nm or more, and this will
be hereinafter referred to as FWM suppressing guard band
 $\Delta\lambda_g$ in the present embodiment.

15 d. Limiting Band by SPM-GVD Effect

FIG. 15 shows the construction of a regenerative
repeater system or optical transmission system to which
the optical wavelength multiplex transmission method of
the seventh embodiment of the present invention is
20 applied. Referring to FIG. 15, the regenerative
repeater system shown includes a transmitter 11 for
converting an electric signal into an optical signal or
signal light and performing optical wavelength
multiplexing using the construction (transmission
25 circuit 1) described hereinabove with reference to FIG.
2, and a plurality of in-line amplifiers 12 inserted
substantially at a fixed distance $L_{in-line}$ in an optical

1 transmission line (optical fiber 2) for amplifying a
signal attenuated by line loss.

The regenerative repeater system further
includes a plurality of regenerative-repeaters 13
5 interposed substantially at a fixed distance L_{R-R} ,
greater than the distance $L_{in-line}$ between the in-line
repeaters 12 in the optical transmission line (optical
fiber 2). The regenerative-repeaters 13 are provided to
regenerate pulse signals from signal light in the
10 optical transmission line before the signal light is
degraded by an influence of noise relying upon the line
characteristic into a condition in which signals thereof
cannot be discriminated from one another, and have three
functions represented by words beginning with R
15 including reshaping, retiming and regenerating.
Therefore, such a regenerative-repeater is also called
3R repeater.

The regenerative repeater system further
includes a receiver 14 for demultiplexing signal light.
20 which has been multiplexed by the construction
(reception circuit 4) described hereinabove with
reference to FIG. 2 and converting the signal light
waves obtained by the demodulation into electric
signals.

25 In the present embodiment, the transmitter 11
and the receiver 14 are interconnected by way of the
optical fiber 2 with the plurality of in-line repeaters

1 12 and regenerative-repeaters 13 interposed in the
optical fiber 2 to construct the optical transmission
system or regenerative-repeater system 10 according to
the optical amplifier multi-repeater WDM method.

5 By the way, in the case of the optical
transmission system 10 of such a construction as
described above, the distance L_{R-R} between the
regenerative-repeaters 13 are restricted principally by
two factors including 1. optical signal to noise
10 degradation by ASE accumulation at the in-line repeaters
12 and 2. waveform degradation by an SPM-GVD effect
caused by a Kerr-effect in the optical fiber 2.
Simultaneously, the lower limit to the input power into
the optical fiber 2 is limited by the optical signal to
15 noise ratio while the upper limit is limited by the SPM-
GVD effect. It is to be noted that, for evaluation of
waveform degradation by an SPM-GVD effect, generally a
simulation which involves solution of a non-linear
Schroedinger equation using the split step Fourier
20 method is effective.

FIG. 19 illustrates an example of a relationship
between the input power to the optical fiber 2 and the
distance L_{R-R} between the regenerative-repeaters 13
when the transmission rate is 10 Gbps. the distance
25 $L_{in-line}$ between the in-line repeaters 12 is 70 km and
only one wave is transmitted. If it is assumed that the
variation of the optical output from each optical

1 amplifier (in-line repeater 12) is ± 2 dB, where an
allowable dispersion value D_{allow} is $D_{allow} = \pm 1$
ps/(nm·km), the maximum value of the distance L_{R-Rep}
between the regenerative-repeaters 13 is 280 km, and
5 where the allowable dispersion value D_{allow} is $D_{allow} =$
 ± 2 ps/(nm·km), the maximum value of the distance L_{R-Rep}
between the regenerative-repeaters 13 is 210 km. In
order to realize long-haul transmission, it is necessary
to set the allowable dispersion value low and set the
10 input power to the optical fiber 2 high.

•Relationship between Channel Arrangement and
Characteristic Required for Optical Fiber

Three required characteristics for a DSF
(optical fiber 2) must be taken into consideration when
15 it is tried to achieve optical transmission based on the
WDM method, including 1. the zero-dispersion wavelength
 λ_0 , 2. the zero-dispersion wavelength deviation $\pm \Delta \lambda_0$,
and 3. the dispersion slope (second-order dispersion)
 $dD/d\lambda$ as described hereinabove. Here, the zero-
20 dispersion wavelength deviation $\pm \Delta \lambda_0$ signifies not only
a dispersion involved in production of a DSF but also a
maximum deviation width of the zero-dispersion
wavelength λ_0 in the longitudinal direction of the
optical fiber 2 within the distance L_{R-Rep} between the
25 regenerative-repeaters 13.

FIG. 20 illustrates a result of measurement of
the FWM production efficiency η when two signal light

1 waves were inputted to an actual DSF and the wavelength
2 λ_2 of one of the two signal light waves was fixed to
3 1.557 nm while the wavelength λ_1 of the other signal
4 light wave was varied. In FIG. 20, the result of
5 measurement is indicated by a solid line interconnecting
6 blank round marks. In the measurement, the optical
7 fiber length was 60 km, and the power of each signal
8 light wave was +4 dBm. Comparison with another result
9 of calculation (indicated by a broken line in FIG. 20)
10 conducted with the zero-dispersion wavelength λ_0 fixed
11 to a fixed value reveals that the measurement values
12 indicated by a solid line in FIG. 20 are distributed
13 over a wider wavelength range. This signifies that the
14 zero-dispersion wavelength λ_0 of the actual DSF exhibits
15 a deviation in the longitudinal direction of the DSF.

Taking the foregoing points described above into
consideration, in the optical wavelength multiplex
transmission method of the seventh embodiment of the
present invention, signal light waves of different
20 channels are arranged in such a manner, for example, as
21 illustrated in FIG. 13. It is to be noted that, in the
22 present embodiment, description will be given of the
23 case wherein signal light waves of four channels are
24 wavelength multiplexed and transmitted.

25 In particular, referring to FIG. 13, taking the
zero-dispersion wavelength λ_0 of the optical fiber 2 and
the zero-dispersion wavelength deviation $\pm\Delta\lambda_0$ in the

1 longitudinal direction of the optical fiber 2 into
consideration. signal light waves of four channels to be
multiplexed are arranged at an equal spacing $\Delta\lambda_s$ on the
shorter wavelength side than a short wavelength end $\lambda_0 -$
5 $\Delta\lambda_0$ of the range of the zero-dispersion wavelength
deviation of the optical fiber 2.

In this instance, an FWM suppressing guard band
 $\Delta\lambda_g$ is provided on the shorter wavelength side than the
short wavelength end $\lambda_0 - \Delta\lambda_0$ of the zero-dispersion
10 wavelength deviation range of the optical fiber 2, and
signal light waves of four channels (wavelengths λ_1 to
 λ_4 in the channels 1 to 4) are arranged on the further
shorter wavelength side than the wavelength $\lambda_0 - \Delta\lambda_0 -$
 $\Delta\lambda_g$. In the present embodiment, the wavelength λ_1 of
15 the channel 1 is set to the position spaced by $\Delta\lambda_0 + \Delta\lambda_g$
on the shorter wavelength side than the zero-dispersion
wavelength λ_0 of the DSF (optical fiber 2). In other
words, the wavelength $\lambda_0 - \Delta\lambda_0 - \Delta\lambda_g$ is set so as to
coincide with the wavelength λ_1 of the channel 1.

20 Further, in the present embodiment, signal light
waves of four channels are arranged within the
transmissible bandwidth $\Delta\lambda_{SPM-GVD}$ defined by the
allowable dispersion value D_{allow} determined from an
SPM-GVD effect in the optical fiber 2. In particular,
25 as seen from FIG. 13, the transmissible wavelength range
of signal light is a range within $\Delta\lambda_{SPM-GVD} =$
 $|D_{allow}|/(dD/d\lambda)$ on the shorter wavelength side than the

1 long wavelength end $\lambda_0 + \Delta\lambda_0$ of the zero-dispersion
wavelength deviation range of the optical fiber 2. In
this instance, in order to allow transmission of four
waves and allow the zero-dispersion wavelength deviation
5 $\Delta\lambda_0$ to be set as great as possible, the wavelength
 $\lambda_{SPM-GVD}$ ($= (\lambda_0 + \Delta\lambda_0) - \Delta\lambda_{SPM-GVD}$) and the wavelength
 λ_4 of the channel 4 are set so as to coincide with each
other.

Further, in the present embodiment, signal light
10 waves of four channels are arranged within a gain band
 $\Delta\lambda_{EDFA}$ (such a range of 1.550 to 1.560 nm as
illustrated, for example, in FIG. 16) of an EDFA
(optical amplifier arranged in each in-line repeater 12)
connected to the optical fiber 2.

15 It is to be noted that, though not illustrated
in FIG. 13, when the productivity of semiconductor
lasers (light sources of signal light waves) and/or the
optical wavelength variations of signal light waves
caused by the wavelength control accuracy are taken into
20 consideration, the bandwidth $\Delta\lambda_{WDM}$ within which signal
light waves of a plurality of channels are arranged is
set in an expanded condition in accordance with such
variations.

Here, the example of a signal light arrangement
25 illustrated in FIG. 13 is described in more detail by
way of an example of numerical values. The relationship
between a channel arrangement and characteristics

1 required for a DSF is described for the case wherein,
for example, four signal light waves of the transmission
rate 10 Gbps are arranged at an equal distance of the
wavelength spacing $\Delta\lambda_s = 2$ nm on the shorter wavelength
5 side than the zero-dispersion wavelength λ_0 of the DSF
(optical fiber 2) and the distance $L_{in-line}$ between the
in-line repeaters 12 is set to 70 km while the distance
 L_{R-reg} between the regenerative-repeaters 13 is set to
280 km.

10 First, the relationship of the guard band $\Delta\lambda_g$
with which the crosstalk amounts at all of the channels
are smaller than -30 dB to the wavelength spacing $\Delta\lambda_s$
when the optical fiber length is 70 km and the input
power of each channel is +6 dBm is illustrated in FIG.
15 21. From FIG. 21, it can be seen that, where the
wavelength spacing $\Delta\lambda_s$ is 2 nm (signal light bandwidth
 $\Delta\lambda_{\text{signal}} = 6$ nm), the guard band $\Delta\lambda_g$ is required to be $\Delta\lambda_g$
= 3 nm.

20 In order to effectively utilize the gain band
(1.550 to 1.560 nm) of the EDFA, the wavelength λ_1 of
the channel 1 is set to 1.560 nm which is the longer
wavelength end of the gain band as seen from FIG. 13.
In this instance, the wavelength λ_1 is displaced by $\Delta\lambda_0$
+ $\Delta\lambda_g$ toward the shorter wavelength side from the zero-
25 dispersion wavelength λ_0 of the DSF as described
hereinabove.

Further, since the allowable dispersion value

1 D_{allow} with which the distance $L_{R-\text{rep}}$ between the
 regenerative-repeaters 13 is $L_{R-\text{rep}} = 280 \text{ km}$ is -1
 $\text{ps}/(\text{nm}\cdot\text{km})$ from FIG. 19. the transmissible signal light
 wavelength range is a range within $\Delta\lambda_{\text{SPM-GVD}} =$
 5 $|D_{\text{allow}}|/(dD/d\lambda)$ toward the shorter wavelength side from
 the wavelength $\lambda_0 + \Delta\lambda_0$ as described hereinabove. and in
 order to allow transmission of all of the four waves and
 allow the zero-dispersion wavelength deviation $\Delta\lambda_0$ to be
 set as great as possible. the wavelength $(\lambda_0 + \Delta\lambda_0) -$
 10 $\Delta\lambda_{\text{SPM-GVD}}$ and the wavelength λ_4 of the channel 4 are set
 so as to coincide with each other. From those
 requirements, the values of $\Delta\lambda_{\text{SPM-GVD}}$, $\Delta\lambda_0$ and λ_0 are
 defined in the equations given below:

$$\begin{aligned} \Delta\lambda_{\text{SPM-GVD}} &= |D_{\text{allow}}|/(dD/d\lambda) \\ 15 \quad &= 1 \text{ (ps/(nm}\cdot\text{km))}/0.08 \text{ (ps/nm}^2\cdot\text{km))} \\ &= 12.5 \text{ nm} \end{aligned}$$

$$\Delta\lambda_0 = (\Delta\lambda_{\text{SPM-GVD}} - \Delta\lambda_{\text{WDM}} - \Delta\lambda_g)/2 = 1.75 \text{ nm}$$

$$\lambda_0 = \lambda_1 + \Delta\lambda_0 + \Delta\lambda_g = 1.564.75 \text{ nm}$$

The values given above are values obtained when
 20 the deviation $\Delta\lambda_0$ is in the minimum. It is to be noted
 that. as the dispersion slope $dD/d\lambda$ decreases, $\Delta\lambda_{\text{SPM-GVD}}$
 increases. which allows an increase of the deviation
 $\Delta\lambda_0$.

While the case wherein no optical dispersion
 25 compensator is employed has been described with
 reference to FIG. 13. an alternative case wherein signal
 light arrangement of different channels is performed

1 using an optical dispersion compensator will be
described subsequently. In particular, the optical
wavelength multiplex transmission method of the seventh
embodiment of the present invention can arrange signal
5 light waves of different channels in such a manner, for
example, as illustrated in FIG. 14 using an optical
dispersion compensator. It is to be noted that
description is given also here of the case wherein
signal light waves of four channels are wavelength
10 multiplexed and transmitted.

In particular, signal light waves of four
channels are first arranged outside a transmissible band
 $\Delta\lambda_{\text{SPM-GVD}}$ defined by an allowable dispersion value
 D_{allow} determined from an SPM-GVD effect in the optical
15 fiber 2 as illustrated at an upper half of FIG. 14, and
then the zero-dispersion wavelength λ_0 of the optical
fiber 2 is shifted to λ_0' as illustrated at a lower half
of FIG. 14 using an optical dispersion compensator to
arrange the signal light waves of the four channels
20 apparently in the transmissible band $\Delta\lambda_{\text{SPM-GVD}}$.

In this instance, the signal light waves of the
four channels are arranged, before they are shifted by
the optical dispersion compensator, at the equal spacing
 $\Delta\lambda_s$ on the shorter wavelength side than the wavelength
25 $\lambda_0 - \Delta\lambda_s - \Delta\lambda_g$ and within the gain bandwidth $\Delta\lambda_{\text{EDFA}}$ of
the EDFA similarly as in the example of an arrangement
described hereinabove with reference to FIG. 13. It is

1 to be noted that the wavelength λ_1 of the channel 1 is
set so that it may coincide with the wavelength $\lambda_0 - \Delta\lambda_0$
- $\Delta\lambda_g$ displaced by $\Delta\lambda_0 + \Delta\lambda_g$ toward the shorter
wavelength side from the zero-dispersion wavelength λ_0 .

5 Then, by shifting the actual zero-dispersion
wavelength λ_0 by $\Delta\lambda_{0c}$ toward the shorter wavelength side
by means of the optical dispersion compensator, the
signal light waves of the four channels are arranged
apparently in the transmissible bandwidth $\Delta\lambda_{spM-GUD}$ as
10 seen in the lower half of FIG. 14.

It is to be noted that, though not illustrated
in FIG. 14, when the productivity of semiconductor
lasers (light sources of signal light waves) and/or the
optical wavelength variations of signal light waves
15 caused by the wavelength control accuracy are taken into
consideration, the bandwidth $\Delta\lambda_{wDM}$ within which signal
light waves of a plurality of channels are to be
arranged is set in an expanded condition in accordance
with such variations.

20 Further, though not illustrated in FIG. 14,
where an optical dispersion compensator is employed as
described above, taking the dispersion compensation
amount deviation range $\pm\delta\lambda_{0c}$ of the optical dispersion
compensator into consideration, the signal light
25 bandwidth $\Delta\lambda_{wDM}$ is set expanding the same by the
dispersion compensation amount deviation range $\delta\lambda_{0c}$ on
the opposite sides of the longer wavelength side and the

1 shorter wavelength side. Further, for the optical
dispersion compensator, such optical dispersion
compensators, for example, as hereinafter described in
connection with ninth to fifteenth embodiments of the
5 present invention can be employed.

Here, the example of a signal light arrangement
illustrated in FIG. 14 is described using an example of
detailed values. It is to be noted that the case
wherein the zero-dispersion wavelength deviation $\Delta\lambda_0$ of
10 the optical fiber 2 can be set to the maximum using an
optical dispersion compensator having a dispersion value
of the opposite positive or negative sign to that of the
transmission line of a signal band and the dispersion
compensation wavelength shift amount $\Delta\lambda_{bc}$ can be
15 minimized from the points of the size and the optical
loss of the optical dispersion compensator is considered
here. Further, as regards numerical values, it is
assumed here that they are similar to those described
hereinabove with reference to FIG. 13.

20 The zero-dispersion wavelength deviation $\Delta\lambda_0$ is
allowed to be set to the maximum when an area over which
the range of $\Delta\lambda_{spm-gub}$ toward the longer wavelength side
from the lower limit of the zero-dispersion wavelength
deviation and the range of $\Delta\lambda_{spm-gub}$ toward the shorter
25 wavelength side from the lower limit of the zero-
dispersion wavelength deviation overlap with each other
coincides with the signal light bandwidth $\Delta\lambda_{wom}$ as seen

1 from the lower half of FIG 14 In short,

$$\begin{aligned}\Delta\lambda_0(\text{max}) &= (2 \cdot \Delta\lambda_{\text{SPM-GVD}} - \Delta\lambda_{\text{WDM}})/2 \\ &= (2 \times 12.5 - 6)/2 = 9.5 \text{ nm}\end{aligned}$$

and in this instance, the apparent zero-dispersion
5 wavelength λ_0' after dispersion compensation is
positioned at the center of the signal light bandwidth
 $\Delta\lambda_{\text{WDM}}$.

Before dispersion compensation, as shown in the
upper half of FIG. 14, the wavelength λ_1 of the channel
10 1 is displaced by $\Delta\lambda_0 + \Delta\lambda_g$ toward the shorter
wavelength side from the zero-dispersion wavelength λ_0
from the requirement for FWM suppression. Accordingly,

$$\lambda_0 = \lambda_1 + \Delta\lambda_0 + \Delta\lambda_g = 1.572.5 \text{ nm}$$

and accordingly, $\lambda_0 \pm \Delta\lambda_0 = 1.572.5 \pm 9.5 \text{ nm}$.

15 In this instance, the dispersion compensation
wavelength shift amount $\Delta\lambda_{\text{DC}}$ is $\lambda_0 - \lambda_0'$, and is
calculated in the following manner:

$$\begin{aligned}\Delta\lambda_{\text{DC}} &= (2 \cdot \Delta\lambda_0 - \Delta\lambda_{\text{SPM-GVD}}) + \Delta\lambda_g + \Delta\lambda_{\text{WDM}} \\ &= (2 \times 9.5 - 12.5) + 3 + 6 = 15.5 \text{ nm}\end{aligned}$$

20 Optical dispersion compensators are required to
have a higher dispersion, a lower loss and a smaller
size, and various types of optical dispersion
compensators including the dispersion compensation fiber
type, the transversal filter type and the optical
25 resonator type have been proposed. Here, optical
dispersion compensators of the optical dispersion
compensation type, which will be hereinafter described

1 in connection with the ninth to fifteenth embodiments of
the present invention. are employed.

It is to be noted that, since the example
illustrated in FIG. 14 requires an optical dispersion
5 compensator having a positive dispersion value, if, for
example, an ordinary single mode fiber (dispersion value
 $D_{0c} = 18 \text{ ps}/(\text{nm} \cdot \text{km})$) is employed, then the required
fiber length L_{0c} is given in the following manner:

$$\begin{aligned} L_{0c} &= (\Delta\lambda_{0c} \cdot dD/d\lambda \cdot L_R - r_{0c})/D_{0c} \\ 10 \quad &= (15.5 \times 0.08 \times 280)/18 = 19.3 \text{ km} \end{aligned}$$

While, in the examples of FIGS. 13 and 14
described hereinabove, detailed examples have been
described for the cases wherein the zero-dispersion
wavelength deviation $\Delta\lambda_0$ has the minimum value and the
15 maximum value, respectively, the relationship of the
zero-dispersion wavelength λ_0 and the dispersion
compensation wavelength shift amount $\Delta\lambda_{0c}$ to the
deviation $\Delta\lambda_0$ where signal light waves are arranged on
the shorter wavelength side than the zero-dispersion
20 wavelength λ_0 is illustrated in FIG. 22. In FIG. 22,
the relationship where the wavelength spacing $\Delta\lambda_s$ is $\Delta\lambda_s$
 $= 2 \text{ nm}$ and the guard band $\Delta\lambda_g$ is $\Delta\lambda_g = 3 \text{ nm}$ is indicated
by a solid line. Meanwhile, the relationship where the
wavelength spacing $\Delta\lambda_s$ is $\Delta\lambda_s = 3 \text{ nm}$ is indicated by a
25 broken line. In this instance, from FIG. 13, since it
is only required that the zero-dispersion wavelength λ_0
and the wavelength λ_1 of the channel 1 do not coincide

1 with each other, the guard band $\Delta\lambda_g$ is set to $\Delta\lambda_g = 1$
nm.

In this manner, with the optical wavelength
multiplex transmission method of the seventh embodiment,
5 signal light waves of different channels can be arranged
without being influenced by FWM in an optical amplifier
multi-repeater WDM method which makes use of a band in
the proximity of the zero-dispersion wavelength λ_0 of
the optical fiber 2, and simultaneously, a required
10 characteristic regarding the zero-dispersion wavelength
 λ_0 of an optical fiber transmission line to be laid can
be made definite and a channel arrangement method for
signal light and a transmission line designing method in
an optical amplifier multi-repeater WDM method can be
15 established.

Particularly, according to the present
embodiment, by arranging signal light waves of different
channels on the shorter wavelength side than the
wavelength $\lambda_0 - \Delta\lambda_0 - \Delta\lambda_g$ taking the zero-dispersion
20 wavelength deviation range and the FWM suppressing guard
band into consideration, the zero-dispersion wavelength
deviation in the longitudinal direction of the optical
fiber 2 is taken into consideration and controlled, and
simultaneously, an influence of FWM is suppressed.
25 Consequently, an influence from another channel by
crosstalk is suppressed, and a high degree of
transmission accuracy can be maintained.

1 Further, according to the present invention, in
addition to the fact that signal light arrangement can
be performed taking waveform degradation by an SPM-GVD
effect into consideration, the powers of the signal
5 light waves can be made equal and the received
characteristics for the signal light waves can be made
equal by arranging the signal light waves of the
different channels within the gain bandwidth $\Delta\lambda_{EDFA}$ of
the EDFA.

10 Furthermore, by setting the bandwidth $\Delta\lambda_{WDM}$,
within which signal light waves are to be arranged, in
an expanded condition in accordance with optical
wavelength variations of the signal light waves of the
different channels, the variations of the signal light
15 waves caused by the productivity and/or the wavelength
control accuracy of light sources for the signal light
waves such as semiconductor lasers are taken into
consideration, and where an optical dispersion
compensator is employed, by setting the bandwidth $\Delta\lambda_{WDM}$,
20 within which the signal light waves are to be arranged,
expanding the same by the dispersion compensation amount
deviation range $\delta\lambda_{DC}$ of the optical dispersion
compensator on the opposite sides of the longer
wavelength side and the shorter wavelength side, also
25 the dispersion compensation amount deviation of the
optical dispersion compensator is taken into
consideration. Consequently, optical transmission of

1 higher reliability can be achieved

It is to be noted that, while, in the seventh
embodiment described above, the case wherein signal
light waves of four channels are to be arranged is
5 described above, the present invention is not limited to
this.

H. Eighth Embodiment

Subsequently, an optical wavelength multiplex
transmission method of an eighth preferred embodiment of
10 the present invention. FIG. 23 illustrates a signal
light arrangement of a plurality of channels of the
optical wavelength multiplex transmission method while
FIG. 24 illustrates a modification to the signal light
arrangement illustrated in FIG. 23, and FIG. 25
15 illustrates the relationship of the zero-dispersion
wavelength and the dispersion compensation amount to the
zero-dispersion wavelength deviation in the optical
wavelength multiplex transmission method. It is to be
noted that also the optical wavelength multiplex
20 transmission method of the eighth embodiment is applied
to a system similar to the regenerative-repeater system
or optical transmission system described hereinabove
with reference to FIG. 15, and overlapping description
of the same will be omitted herein to avoid redundancy

25 While, in the seventh embodiment described
above, description has been given of the case wherein
signal light waves of different channels are arranged on

1 the shorter wavelength side than the zero-dispersion
wavelength λ_0 of the optical fiber 2, in the eighth
embodiment, signal light waves of different channels are
arranged on the longer wavelength side than the zero-
5 dispersion wavelength λ_0 of the optical fiber 2. Then,
after the wavelength λ_1 of the channel 1 is set to the
shorter wavelength end 1.550 nm of the gain bandwidth of
the EDFA, the relationship between the channel
arrangement and characteristics required for the DSF
10 (optical fiber 2) are determined by the quite same means
as that of the seventh embodiment described hereinabove
with reference to FIG. 13.

In particular, taking the zero-dispersion
wavelength λ_0 of the optical fiber 2 and the zero-
15 dispersion wavelength deviation $\pm\Delta\lambda_0$ in the longitudinal
direction of the optical fiber 2 into consideration,
signal light waves of fourth channels to be multiplexed
are arranged at an equal spacing $\Delta\lambda_s$ on the longer
wavelength side than the longer wavelength end $\lambda_0 + \Delta\lambda_0$
20 of the zero-dispersion wavelength deviation range of the
optical fiber 2 as illustrated in FIG. 23.

In this instance, an FWM suppressing guard band
 $\Delta\lambda_g$ is provided on the longer wavelength side than the
longer wavelength end $\lambda_0 + \Delta\lambda_0$ of the zero-dispersion
25 wavelength deviation range of the optical fiber 2, and
the signal light waves of the four channels (for the
channels 1 to 4 of the wavelengths λ_1 to λ_4) are

1 arranged on the further longer wavelength side than the
wavelength $\lambda_0 + \Delta\lambda_0 + \Delta\lambda_g$. In the present embodiment,
the wavelength λ_1 of the channel 1 is set at the
position displaced by $\Delta\lambda_0 + \Delta\lambda_g$ toward the longer
5 wavelength side from the zero-dispersion wavelength λ_0
of the DSF (optical fiber 2), that is, the wavelength λ_0
 $+ \Delta\lambda_0 + \Delta\lambda_g$ is set so as to coincide with the wavelength
 λ_1 of the channel 1.

Further, in the present embodiment, signal light
10 waves of four channels are arranged in a transmissible
band $\Delta\lambda_{SPM-GVD}$ defined by an allowable dispersion value
 D_{allow} determined from an SPM-GVD in the optical fiber
2. In particular, as illustrated in FIG. 23, the
transmissible signal light wavelength range is a range
15 within $\Delta\lambda_{SPM-GVD} = |D_{allow}| / (dD/d\lambda)$ displaced toward the
longer wavelength side from the shorter wavelength end
 $\lambda_0 - \Delta\lambda_0$ of the zero-dispersion wavelength deviation
range of the optical fiber 2. In this instance, in
order to allow the four waves to be transmitted and
20 allow the zero-dispersion wavelength deviation $\Delta\lambda_0$ to be
set as great as possible, the wavelength $\lambda_{SPM-GVD}$ ($= (\lambda_0$
 $- \Delta\lambda_0) + \Delta\lambda_{SPM-GVD}$) and the wavelength λ_4 of the channel
4 are set so as to coincide with each other.

Further, in the present embodiment, the signal
25 light waves of the four channels are arranged within a
gain bandwidth $\Delta\lambda_{EDFA}$ (for example, such a range of
1.550 to 1.560 nm as shown in FIG. 16) of an EDFA

1 connected to the optical fiber 2.

It is to be noted that, though not illustrated in FIG. 23, also in the present embodiment, when the productivity of semiconductor lasers (light sources of
5 signal light waves) and/or the optical wavelength variations of the signal light waves caused by the wavelength control accuracy are taken into consideration, the bandwidth $\Delta\lambda_{WDM}$ within which signal light waves of a plurality of channels are to be
10 arranged is set in an expanded condition in accordance with such variations.

By the way, while the case wherein an optical dispersion compensator is not employed is described above with reference to FIG. 23, another case wherein
15 signal light arrangement of different channels is performed using an optical dispersion compensator will be described subsequently. In other words, with the optical wavelength multiplex transmission method of the eighth embodiment of the present invention, signal light
20 waves of different channels can be arranged, for example, in such a manner as illustrated in FIG. 24 by using an optical dispersion compensator.

In particular, signal light waves of four channels are first arranged outside a transmissible band
25 $\Delta\lambda_{SPM-GVD}$ defined by an allowable dispersion value D_{allow} determined by an SPM-GVD effect in the optical fiber 2 as illustrated in the upper half of FIG. 24. and

1 then the zero-dispersion wavelength λ_0 of the optical
fiber 2 is shifted to λ_0' using an optical dispersion
compensator as illustrated in the lower half of FIG. 24
to arrange the signal light waves of the four channels
5 apparently within the transmissible band $\Delta\lambda_{SPM-GVD}$.

In this instance, the signal light waves of the
four channels are arranged, before shifting by the
optical dispersion compensator is performed, at an equal
spacing $\Delta\lambda_s$ on the longer wavelength side than the
10 wavelength $\lambda_0 + \Delta\lambda_0 + \Delta\lambda_g$ and within the gain bandwidth
 $\Delta\lambda_{EDFA}$ of the EDFA similarly as in the example of an
arrangement described hereinabove with reference to FIG.
23. It is to be noted that the wavelength λ_1 of the
channel 1 is set so as to coincide with the wavelength
15 $\lambda_0 + \Delta\lambda_0 + \Delta\lambda_g$ displaced by $\Delta\lambda_0 + \Delta\lambda_g$ toward the longer
wavelength side from the zero-dispersion wavelength λ_0 .

Then, the actual zero-dispersion wavelength λ_0
is shifted by $\Delta\lambda_{DC}$ ($= \lambda_0' - \lambda_0$) toward the longer
wavelength side by means of the optical dispersion
20 compensator thereby to apparently arrange the signal
light waves of the four channels within the
transmissible band $\Delta\lambda_{SPM-GVD}$.

It is to be noted that also FIG. 24 illustrates
the case wherein, as described hereinabove in connection
25 with the seventh embodiment with reference to FIG. 14,
an area over which the range of $\Delta\lambda_{SPM-GVD}$ displaced
toward the longer wavelength side from the lower limit

1 of the zero-dispersion wavelength deviation and the
range of $\Delta\lambda_{SPM-GVD}$ displaced toward the shorter
wavelength side from the lower limit of the zero-
dispersion wavelength deviation overlap with each other
5 is made coincide with the signal light bandwidth $\Delta\lambda_{SDM}$
so that the zero-dispersion wavelength deviation $\Delta\lambda_0$ is
allowed to be set to the maximum as described
hereinabove in connection with the seventh embodiment
with reference to FIG 14.

10 Further, though not illustrated in FIG. 24, when
the productivity of semiconductor lasers (light sources
of the signal light waves) and/or the optical wavelength
variations of the signal light waves caused by the
wavelength control accuracy are taken into
15 consideration, the bandwidth $\Delta\lambda_{SDM}$ within which signal
light waves of a plurality of channels are to be
arranged is set in an expanded condition in accordance
with such variations.

Further, though not illustrated in FIG. 24,
20 where an optical dispersion compensator is employed as
described above, taking the dispersion compensation
amount deviation range $\pm\delta\lambda_{DC}$ of the optical dispersion
compensator into consideration, the signal light
bandwidth $\Delta\lambda_{SDM}$ is set expanding the same by the
25 dispersion compensation amount deviation range $\delta\lambda_{DC}$ on
the opposite sides of the longer wavelength side and the
shorter wavelength side. Further, for the optical

1 dispersion compensator, such optical dispersion
compensators, for example, as hereinafter described in
connection with ninth to fifteenth embodiments of the
present invention can be employed.

5 While, in the examples of FIGS. 23 and 24
described hereinabove, the cases wherein the zero-
dispersion wavelength deviation $\Delta\lambda_0$ has the minimum
value and the maximum value, respectively, have been
described, the relationship of the zero-dispersion
10 wavelength λ_0 and the dispersion compensation wavelength
shift amount $\Delta\lambda_{DC}$ to the deviation $\Delta\lambda_0$ where signal
light waves are arranged on the longer wavelength side
than the zero-dispersion wavelength λ_0 is illustrated in
FIG. 25. Also in FIG. 25, similar numerical values to
15 those described hereinabove in connection with the
seventh embodiment with reference to FIG. 22 are
applied. However, in FIG. 25, the slope of the zero-
dispersion wavelength λ_0 relative to the deviation $\Delta\lambda_0$
is set opposite to that illustrated in FIG. 22 in order
20 to arrange the signal light waves on the longer
wavelength side than the zero-dispersion wavelength λ_0 .

In this manner, similar advantages to those
described hereinabove in connection with the seventh
embodiment can be achieved by the optical wavelength
25 multiplex transmission method of the eighth embodiment.

It is to be noted that, while, in the eighth
embodiment described above, the case wherein the signal

1 light waves of the four channels are to be arranged has
been described. the present invention is not limited to
this, and the signal light waves of the channels can be
arranged on the opposite sides of the zero-dispersion
5 wavelength λ_a . In this instance, when optical
dispersion compensation is involved, different optical
dispersion compensators of the opposite positive and
negative signs must necessarily be used for the channels
on the shorter wavelength side and the longer wavelength
10 side of the zero-dispersion wavelength λ_a .

I. Ninth Embodiment

Subsequently, an optical dispersion compensation
method as a ninth preferred embodiment of the present
invention will be described. FIG. 26 shows, in block
15 diagram, an optical dispersion compensation system to
which the optical dispersion compensation method is
applied. Referring to FIG. 26, the optical dispersion
compensation system shown is denoted at 20 and includes
a transmitter 21 for converting an electric signal into
20 an optical signal and transmitting the optical signal,
and a plurality of repeaters 22 inserted in an optical
transmission line (optical fiber 2). Such an in-line
repeater or a regenerative-repeater as described
hereinabove may be employed for the repeaters 22.

25 The optical dispersion compensation system 20
further includes a receiver 23 for converting a received
optical signal into an electric signal. The transmitter

1 21 and the receiver 23 are interconnected by way of the
optical fiber 2 with the repeaters 22 interposed in the
optical fiber 2. In the optical transmission system 20,
signal light from the transmitter 21 is transmitted to
5 the receiver 23 by way of the repeaters 22 and the
optical fiber 2.

The optical dispersion compensation system 20
further includes two kinds of optical dispersion
compensator units including an optical dispersion
10 compensator unit 24A having a positive dispersion amount
+B and another optical dispersion compensator unit 24B
having a negative dispersion amount -B. The two kinds
of optical dispersion compensator units 24A and 24B are
prepared in advance and are interposed in the optical
15 transmission system 20, that is, at any location of the
optical fiber 2, the transmitter 21, the repeaters 22
and the receiver 23.

By the way, where the optical transmission
system 20 is such an optical amplifier regenerative-
20 repeater system as described hereinabove with reference
to FIG. 15, since the allowable dispersion value
decreases as the regenerative-repeater span increases as
described hereinabove with reference to FIG. 19, an
optical dispersion compensator for restraining the
25 arrangement positions of the channels (signal light)
within an allowable dispersion range for the arrangement
positions is essentially required.

1 Further, while, in the first to eighth
embodiments described hereinabove, the zero-dispersion
wavelength of the optical fiber 2 and the signal light
wavelength are separated from each other in order to
5 eliminate otherwise possible crosstalk by FWM in the WDM
method which makes use of a band in the proximity of the
zero-dispersion wavelength of the optical fiber 2,
dispersion compensation by the corresponding amount
(refer particularly to the examples of FIGS. 14 and 24
10 in the seventh and eighth embodiments) is required.
Such dispersion compensation is required also for one-
wave transmission or SMF transmission.

Particularly in the case of an optical
communication system on land, since the repeater span is
15 not fixed and besides the zero-dispersion wavelength of
an actual optical fiber exhibits a deviation in the
longitudinal direction, it is difficult to set the
dispersion amounts of different repeater sections equal
to each other. Therefore, when a signal light
20 wavelength is set in the proximity of the zero-
dispersion wavelength of the DSF (optical fiber 2),
there is even the possibility that the positive or
negative sign of the dispersion amount may be different
among different repeater sections.

25 Thus, in the present ninth embodiment, in order
to compensate for the dispersion amount of the optical
transmission system 20, the two kinds of optical

1 dispersion compensator units 24A and 24B prepared in
advance are inserted into the optical transmission
system 20. and one of the optical dispersion compensator
units 24A and 24B which provides a better transmission
5 characteristic to the optical transmission system 20 is
selected and incorporated into the optical transmission
system 20.

Consequently, when an accurate dispersion amount
cannot be measured and the zero-dispersion wavelength
10 deviation can be grasped to some degree, the dispersion
amount of the optical transmission system 20 can be
compensated for readily.

On the other hand, when the dispersion amount of
the optical transmission system 20 can be measured, by
15 selecting one of the optical dispersion compensator
units 24A and 24B which has the sign opposite to the
sign of the measured dispersion amount, the dispersion
amount of the optical transmission system 20 can be
compensated for with a higher degree of certainty.

20 In this manner, with the optical dispersion
compensation method of the ninth embodiment, the
waveform degradation by an SPM-GVD effect or the
dispersion amount of a guard band can be compensated for
without designing or producing optical dispersion
25 compensators conforming to individual transmission
lines, and reduction of the number of steps and
reduction of the time until an optical communication

1 system is built up can be realized.

Here, an example of detailed numerical values of
the ninth embodiment will be described. If it is
assumed that the transmission rate is 10 Gbps; the in-
5 line repeater span $L_{in-line}$ is 70 km; the variation of
the optical output of each optical amplifier is ± 2 dB.
from FIG. 19, the maximum regenerative-repeater span is
280 km at the allowable dispersion value $D_{allow} = \pm 1$
ps/(nm·km), and accordingly, the dispersion compensation
10 of ± 280 ps/nm is required for the dispersion amount of
signal light after transmission of 280 km. Therefore,
where the transmission line dispersion amount is, for
example, $+1.200$ ps/nm, when the optical dispersion
compensator units 24A and 24B of the dispersion amounts
15 $+1.000$ ps/nm and -1.000 ps/nm are prepared, if the
optical dispersion compensator unit 24B of the
dispersion amount -1.000 ps/nm is inserted into the
transmission line, then the total dispersion amount is
 $+200$ ps/nm, and therefore, transmission is possible.

20 J. Tenth Embodiment

Subsequently, an optical dispersion compensation
method of a tenth preferred embodiment of the present
invention will be described. FIG. 27 shows, in block
25 diagram, an optical dispersion compensation apparatus to
which the optical dispersion compensation method is
applied. In FIG. 27, like elements are denoted by like
reference characters to those of FIG. 26, and

1 overlapping description thereof is omitted herein to
avoid redundancy

While, in the ninth embodiment described above,
the two kinds of optical dispersion compensator units
5 having the positive dispersion amount $+B$ and the
negative dispersion amount $-B$ are prepared in advance,
in the present tenth embodiment, a plurality of kinds of
optical dispersion compensators 25A and 25B having
different dispersion amounts having different positive
10 and negative signs are prepared in advance.

Here, two kinds of optical dispersion
compensator units 25A and 25B having dispersion amounts
B1 and B2 are prepared each by a plural number, and an
optical dispersion compensator unit 25 which is
15 constituted from a combination of such optical
dispersion compensation units 25A and 25B is inserted
into the optical transmission system 20, that is, at any
portion of the optical fiber 2, the transmitter 21, the
repeaters 22 and the receiver 23.

20 Further, in the present embodiment, at a cite at
which an optical communication system is to be
installed, the two kinds of optical dispersion
compensator units 25A and 25B are inserted into the
optical transmission system 20 changing the number and
25 the combination of units to be installed, and the
transmission characteristic, particularly the code error
rate, of the optical transmission system 20 is measured.

1 Then, an optical dispersion compensator unit 25 of the
number and the combination of units which provide a good
transmission characteristic (in FIG. 27, the combination
of three optical dispersion compensator units 25A and
5 one optical dispersion compensator unit 25B) is
selectively determined from the two kinds of optical
dispersion compensator units 25A and 25B and
incorporated into the optical transmission system 20.

Consequently, even when the zero-dispersion
10 wavelength deviation is not known or when the zero-
dispersion and the signal light wavelength are displaced
by a great amount from each other, the dispersion amount
of the optical transmission system 20 can be compensated
for readily and optimally.

15 In contrast, when the dispersion amount of the
optical transmission system 20 can be measured, the
dispersion amount is measured first, and then an optical
dispersion compensator unit 25 of the installation
number and the combination of units with which the
20 dispersion value of signal light falls within a
transmissible dispersion value range is selectively
determined from the two kinds of optical dispersion
compensator units 25A and 25B and incorporated into the
optical transmission system 20. Consequently, the
25 dispersion amount of the optical transmission system 20
can be compensated for so that it can be accommodated
into the allowable dispersion value range with

1 certainty.

In this manner, also with the optical dispersion compensation method of the tenth embodiment, the waveform degradation by an SPM-GVD effect or the dispersion amount of a guard band can be compensated for without designing or producing optical dispersion compensators conforming to individual transmission lines, and reduction of the number of steps and reduction of the time until an optical communication system is built up can be realized.

It is to be noted that, while, in the tenth embodiment described above, description has been given of the case wherein two kinds of optical dispersion compensator units are prepared in advance, the present invention is not limited to this.

Here, an example of detailed numerical values of the tenth embodiment will be described. Where the dispersion compensation of ± 280 ps/nm is required as a dispersion amount for signal light after transmission over the distance of 280 km, if it is assumed that optical dispersion compensator units having the dispersion amounts A1, A2, B1 and B2, for example, of +300 ps/nm, +100 ps/nm, -300 ps/nm and -100 ps/nm, respectively, are prepared in advance, then if three optical dispersion compensator units of the dispersion amount B1 and one optical dispersion compensator unit of the dispersion amount B2 are inserted in combination

1 into the transmission line. then the total dispersion
amount is +200 ps/nm. which allows transmission.

K Eleventh Embodiment

Subsequently, an optical dispersion compensation
5 method of an eleventh preferred embodiment of the
present invention will be described. FIG. 28 shows, in
block diagram, an optical dispersion compensation
apparatus to which the optical dispersion compensation
method is applied, and FIGS. 29 and 30 show different
10 modifications to the optical dispersion compensation
apparatus. It is to be noted that, while, in the ninth
and tenth embodiments described above, description has
been given only of transmission of one signal light
wave, in the present embodiment, description will be
15 given of the case wherein signal light waves
(wavelengths λ_1 to λ_4) of four channels are wavelength
multiplexed and transmitted.

As seen from FIG. 28, also in the present
embodiment, an optical transmission system 20 is
20 constituted from a transmitter 21, a plurality of
repeaters 22 and a receiver 23 interconnected by an
optical fiber 2. However, in the present eleventh
embodiment, the transmitter 21 is constructed so as to
first convert electric signals of different channels
25 into signal light waves having different wavelengths or
frequencies from one another and then multiplex the
signal light waves by optical wavelength multiplexing.

1 To this end, the transmitter 21 includes a plurality of
electro-optical conversion sections (E/01 to E/04) 21a
provided for the individual channels for converting
electric signals of the channels into signal light waves
5 of the predetermined wavelengths, and an optical
multiplexing section 21b for receiving signal light
waves from the electro-optical conversion sections 21a
for the individual channels and multiplexing the
received signal light waves.

10 Meanwhile, the receiver 23 demultiplexes
multiplexed signal light transmitted thereto from the
transmitter 21 by way of the optical fiber 2 and the
repeaters 22 and converts signal light waves obtained by
such demultiplexing individually into electric signals.

15 To this end, the receiver 23 includes an optical
demultiplexing section 23a for demultiplexing and
distributing multiplexed signal light into different
channels, and a plurality of opto-electric conversion
sections (O/E1 to O/E4) 23b provided individually for
20 the channels for converting signal light waves of the
channels distributed thereto from the optical
demultiplexing section 23a into electric signals.

Further, in the present embodiment, optical
dispersion compensator units 25 are interposed between
25 the electro-optical conversion sections 21a and the
optical multiplexing section 21b of the transmitter 21.
In particular, a suitable number and combination of

1 optical dispersion compensator units 25A and 25B are
provided for each of signal light waves of wavelengths
 λ_1 to λ_4 before wavelength multiplexing.

5 In the arrangement shown in FIG. 28, for the
channel of the wavelength λ_1 , only one optical
dispersion compensator unit 25A of the dispersion amount
B1 is provided; for the channel of the wavelength λ_2 ,
one optical dispersion compensator unit 25A of the
dispersion amount B1 and one optical dispersion
10 compensator unit 25B of the dispersion amount B2 are
provided; for the channel of the wavelength λ_3 , one
optical dispersion compensator unit 25A of the
dispersion amount B1 and two optical dispersion
compensator units 25B of the dispersion amount B2 are
15 provided; and for the channel of the wavelength λ_4 , one
optical dispersion compensator unit 25A of the
dispersion amount B1 and three optical dispersion
compensator units 25B of the dispersion amount B2 are
provided.

20 In this instance, when the installation number
and the combination of the optical dispersion
compensator units 25A and 25B arranged for the different
channels are to be selected, as described hereinabove in
the ninth and tenth embodiments, those which provide
25 good transmission characteristics for the individual
channels may be selected by trial and error or, when the
dispersion value of the optical transmission system 20

1 can be measured, those with which the dispersion values
of signal light waves fall within transmissible
dispersion value ranges may be selected in accordance
with a result of the measurement.

5 While the arrangement wherein the optical
dispersion compensator units 25 are provided in the
transmitter 21 are shown in FIG. 28, such optical
dispersion compensator units 25 may be provided
alternatively in each repeater 22 or the receiver 23 as
10 seen in FIG. 29 or 30.

As shown in FIG. 29, where the optical
dispersion compensator units 25 are provided in each
repeater 22, the repeater 22 includes, in addition to an
optical amplifier 22a constituting the repeater 22, an
15 optical demultiplexing section 22b provided at a next
stage to the optical amplifier 22a for demultiplexing
signal light amplified by the optical amplifier 22a into
individual signal light waves of different wavelengths
 λ_1 to λ_4 by wavelength demultiplexing, an optical
20 dispersion compensator unit 25 provided for each of the
channels of signal light waves of the wavelengths λ_1 to
 λ_4 demultiplexed by the optical demultiplexing section
22b and including a suitable installation number and a
suitable combination of optical dispersion compensator
25 units 25A and 25B, and an optical multiplexing section
22c for multiplexing signal light waves of the channels
dispersion compensated for by the optical dispersion

1 compensator units 25 back into signal light by
wavelength multiplexing and sending out the thus
multiplexed signal light into a transmission line. It
is to be noted that the optical demultiplexing section
5 22b, the optical dispersion compensator units 25 and the
optical multiplexing section 22c may be provided
otherwise at a preceding stage to the optical amplifier
22a.

On the other hand, where the optical dispersion
10 compensator units 25 are to be provided in the receiver
23, as shown in FIG. 30, they are interposed between the
optical demultiplexing section 23a and the opto-electric
conversion sections 23b of the receiver 23. In
particular, a suitable installation number and a
15 suitable combination of optical dispersion compensator
units 25A and 25B are provided for each of the signal
light waves of the wavelengths λ_1 to λ_4 after wavelength
demultiplexing.

In this manner, with the optical dispersion
20 compensation method of the eleventh embodiment, also
where the optical transmission system 20 performs
optical wavelength multiplex transmission to multiplex
and transmit signal light waves of different
wavelengths, similar advantages to those described
25 hereinabove in connection with the ninth and tenth
embodiments can be attained by providing a suitable
installation number and a suitable combination of

1 optical dispersion compensator units 25A and 25B for
each wavelength.

It is to be noted that, while the embodiment
described above involves four channels of signal light
5 waves to be multiplexed and two kinds of optical
dispersion compensator units prepared in advance for
dispersion compensation for the individual channels, the
present invention is not limited to this.

L. Twelfth Embodiment

10 Subsequently, an optical dispersion compensation
method of a twelfth preferred embodiment of the present
invention will be described. FIG. 31 shows, in block
diagram, an optical dispersion compensation apparatus to
which the optical dispersion compensation method is
15 applied, and FIGS. 32 and 33 show different
modifications to the optical dispersion compensation
apparatus. It is to be noted that like reference
characters denote like elements to those described
hereinabove, and overlapping description thereof is
20 omitted herein to avoid redundancy.

While, in the eleventh embodiment described
above, description has been given of the case wherein a
suitable installation number and a suitable combination
of optical dispersion compensator units 25A and 25B are
25 provided for each wavelength, in the present twelfth
embodiment, a suitable installation number and a
suitable combination of optical dispersion compensator

1 units 25A and 25B are provided in the optical
transmission system 20 for each channel group including
a plurality of signal light waves (two signal light
waves in the present embodiment).

5 In particular, FIGS. 31 to 33 illustrate
different arrangements wherein optical dispersion
compensator units 25 are provided in the transmitter 21,
each of the repeaters 22 and the receiver 23,
respectively. Where the optical dispersion compensator
10 units 25 are provided in the transmitter 21 as shown in
FIG. 31, the optical multiplexing section 21b of the
transmitter 21 described hereinabove includes an optical
multiplexing section 21c for multiplexing signal light
waves of the wavelengths λ_1 and λ_2 from the electro-
15 optical conversion section 21a, another optical
multiplexing section 21d for multiplexing signal light
waves of the wavelengths λ_3 and λ_4 from the electro-
optical conversion section 21a, and a further optical
multiplexing section 21e for multiplexing two signal
20 light beams multiplexed by the optical multiplexing
sections 21c and 21d.

An optical dispersion compensator unit 25 is
interposed between each of the multiplexing sections 21c
and 21d and the optical multiplexing section 21e. In
25 other words, a suitable installation number and a
suitable combination of optical dispersion compensator
units 25A and 25B are provided for each of channel

1 groups each including two signal light waves.

For example, in the arrangement shown in FIG.
31, for the channel group of the wavelengths λ_1 and λ_2 ,
only one optical dispersion compensator unit 25A of the
5 dispersion amount B1 is provided; and for the channel
group of the wavelengths λ_3 and λ_4 , one optical
dispersion compensator unit 25A of the dispersion amount
B1 and one optical dispersion compensator unit 25B of
the dispersion amount B2 are provided.

10 In this instance, when the installation number
and the combination of the optical dispersion
compensator units 25A and 25B to be arranged for the
different channels are to be selected, as described
hereinabove in the ninth and tenth embodiments, those
15 which provide good transmission characteristics for the
individual channels may be selected by trial and error
or, when the dispersion amount of the optical
transmission system 20 can be measured, those with which
the dispersion values of signal light waves fall within
20 a transmissible dispersion value range may be selected
in accordance with a result of the measurement.

Meanwhile, where the optical dispersion
compensator units 25 are provided in each repeater 22 as
shown in FIG. 32, the repeater 22 includes, in addition
25 to the optical amplifier 22a constituting the repeater
22, an optical demultiplexing section 22d provided at a
next stage to the optical amplifier 22a for

1 demultiplexing signal light amplified by the optical
amplifier 22a into two channel groups including a group
of the wavelengths λ_1 and λ_2 and another group of the
wavelengths λ_3 and λ_4 by wavelength demultiplexing. an
5 optical dispersion compensator unit 25 provided for each
of the channel groups demultiplexed by the optical
demultiplexing section 22d and including a suitable
installation number and a suitable combination of
optical dispersion compensator units 25A and 25B. and an
10 optical multiplexing section 22e for multiplexing signal
light waves of the channel groups dispersion compensated .
for by the optical dispersion compensator units 25 back
into signal light by wavelength multiplexing and sending
out the thus multiplexed signal light into the
15 transmission line. It is to be noted that the optical
demultiplexing section 22d, the optical dispersion
compensator units 25 and the optical multiplexing
section 22e may be provided otherwise at a preceding
stage to the optical amplifier 22a.

20 On the other hand, where the optical dispersion
compensator units 25 are to be provided in the receiver
23. as shown in FIG. 33, the optical demultiplexing
section 23a of the receiver 23 described above includes
an optical demultiplexer 23c for demultiplexing received
25 signal light into a channel group of the wavelengths λ_1
and λ_2 and another channel group of the wavelengths λ_3
and λ_4 . another optical demultiplexing section 23d for

1 demultiplexing the channel group of the wavelengths λ_1
and λ_2 into signal light waves of the wavelengths λ_1 and
and λ_2 , and a further optical demultiplexing section 23e for
demultiplexing the channel group of the wavelengths λ_3
5 and λ_4 into signal light waves of the wavelengths λ_3 and
 λ_4 .

Further, an optical dispersion compensator unit
25 is interposed between the optical demultiplexing
section 23c and each of the optical demultiplexing
10 sections 23d and 23e. In particular, a suitable
installation number and a suitable combination of
optical dispersion compensator units 25A and 25B are
provided for each of the channel groups each including
two signal light waves.

15 In this manner, with the optical dispersion
compensation method of the twelfth embodiment, also
where the optical transmission system 20 performs
optical wavelength multiplex transmission to multiplex
and transmit signal light waves of different
20 wavelengths, similar advantages to those described
hereinabove in connection with the ninth and tenth
embodiments can be attained by providing a suitable
installation number and a suitable combination of
optical dispersion compensator units 25A and 25B for
25 each channel group.

It is to be noted that, while the embodiment
described above involves four channels of signal light

1 waves to be multiplexed and two kinds of optical
dispersion compensator units prepared in advance for
dispersion compensation for the individual channels and
besides involves separation of the channels into two
5 channel groups. the present invention is not limited to
this.

M. Thirteenth Embodiment

Subsequently, an optical dispersion compensation
method of a thirteenth preferred embodiment of the
10 present invention will be described. FIG. 34 shows, in
block diagram, an optical dispersion compensation
apparatus to which the optical dispersion compensation
method is applied, and FIGS. 35 and 36 show different
modifications to the optical dispersion compensation
15 apparatus. It is to be noted that like reference
characters denote like elements to those described
hereinabove, and overlapping description thereof is
omitted herein to avoid redundancy.

While, in the eleventh or twelfth embodiment
20 described above, description has been given of the case
wherein a suitable installation number and a suitable
combination of optical dispersion compensator units 25A
and 25B are provided for each wavelength or for each
channel group. in the present thirteenth embodiment, a
25 suitable installation number and a suitable combination
of optical dispersion compensator units 25A and 25B are
provided in the optical transmission system 20 for all

1 of signal light waves of a plurality of channels (four
channels in the arrangement shown in FIG. 34).

In particular, FIGS. 34 to 36 illustrate
different arrangements wherein an optical dispersion
5 compensator unit 25 is provided in the transmitter 21,
each of the repeaters 22 and the receiver 23,
respectively. Where the optical dispersion compensator
unit 25 is provided in the transmitter 21 as shown in
FIG 34, the optical dispersion compensator unit 25 is
10 provided at a next stage to the optical multiplexing
section 21b of the transmitter 21 and includes a
suitable installation number and a suitable combination
of optical dispersion compensator units 25A and 25B.
For example, in the arrangement shown in FIG. 34, one
15 optical dispersion compensator unit 25A of the
dispersion amount B1 and one optical dispersion
compensator unit 25B of the dispersion amount B2 are
provided.

In this instance, when the installation number
20 and the combination of the optical dispersion
compensator units 25A and 25B to be arranged for all of
the signal light waves are to be selected, as described
hereinabove in the ninth and tenth embodiments, those
which provide good transmission characteristics for the
25 individual channels may be selected by trial and error
or, when the dispersion amount of the optical
transmission system 20 can be measured, those with which

1 the dispersion values of signal light waves fall within
a transmissible dispersion value range may be selected
in accordance with a result of the measurement

Meanwhile, where the optical dispersion
5 compensator unit 25 is provided in each repeater 22 as
shown in FIG. 35, it is located at a next stage to the
optical amplifier 22a constituting the repeater 22 and
includes a suitable installation number and a suitable
combination of optical dispersion compensator units 25A
10 and 25B. It is to be noted that the optical dispersion
compensator unit 25 may be provided otherwise at a
preceding stage to the optical amplifier 22a.

On the other hand, where the optical dispersion
compensator unit 25 is to be provided in the receiver
15 23, as shown in FIG. 36, it is located at a preceding
stage to the optical demultiplexing section 23a of the
receiver 23 and includes a suitable installation number
and a suitable combination of optical dispersion
compensator units 25A and 25B.

20 In this manner, with the optical dispersion
compensation method of the thirteenth embodiment, also
where the optical transmission system 20 performs
optical wavelength multiplex transmission to multiplex
and transmit signal light waves of different
25 wavelengths, similar advantages to those described
hereinabove in connection with the ninth and tenth
embodiments can be attained by providing a suitable

1 installation number and a suitable combination of
optical dispersion compensator units 25A and 25B for all
of signal light waves of the channels.

It is to be noted that, while the embodiment
5 described above involves four channels of signal light
waves to be multiplexed and two kinds of optical
dispersion compensator units prepared in advance for
dispersion compensation for the individual channels, the
present invention is not limited to this.

10 Further, in the tenth to thirteenth embodiments
described above, it is important to design the
dispersion values of the involved optical dispersion
compensator units taking the wavelength spacing between
the channels and the dispersion slope $dD/d\lambda$ of the
15 transmission line into consideration and reduce the
number of types of optical dispersion compensator units
as small as possible.

N. Fourteenth Embodiment

Subsequently, an optical dispersion compensation
20 method of a fourteenth preferred embodiment of the
present invention will be described. FIG. 37 shows, in
block diagram, an optical dispersion compensation
apparatus to which the optical dispersion compensation
method is applied, and FIGS. 38(a) and 38(b) show a
25 modification to the optical dispersion compensation
apparatus while FIG. 39 show another modification to the
optical dispersion compensation apparatus and FIG. 40

1 shows an example of the construction of a packet based
on the modified optical dispersion compensation
apparatus of FIG. 39. It is to be noted that like
reference characters denote like elements to those
5 described hereinabove, and overlapping description
thereof is omitted herein to avoid redundancy.

While, in the ninth to thirteenth embodiments
described above, description has been given of the
arrangement means for the optical dispersion compensator
10 units 24A, 24B, 25, 25A and 25B, in the present
fourteenth embodiment, examples of a detailed
construction and insertion installation means of the
optical dispersion compensator units 25, 25A and 25B
themselves will be described.

15 For example, as shown in FIG. 37, an optical
amplifier 26 is additionally provided at a preceding
stage or a next stage to each of optical dispersion
compensator units 25A and 25B constituting an optical
dispersion compensator unit 25 for compensating the
20 optical loss by the optical dispersion compensator unit
25A or 25B.

By the way, various types of optical dispersion
compensators have been proposed so far including the
dispersion compensating fiber type, the transversal
25 filter type and the optical resonator type. While
dispersion compensation fibers having a dispersion value
higher than $-100 \text{ ps}/(\text{nm} \cdot \text{km})$ are manufactured at present

1 by contriving the shape of the core. with such
dispersion compensation fibers. the optical loss is high
although a dispersion compensation amount can be
adjusted readily by the length of the fiber.

5 Thus, where the optical dispersion compensator
units 25A and 25B are integrated with an optical
amplifier 26 such as an EDFA as in the fourteenth
embodiment, the optical loss of the dispersion
compensation fiber can be compensated for.

10 It is to be noted that, while an optical
amplifier 26 is additionally provided for each optical
dispersion compensator unit 25A or 25B in FIG. 37, only
one optical amplifier 26 may otherwise be provided for
each group (optical dispersion compensation unit 25) of
15 optical dispersion compensator units 25A and 25B as
shown in FIG. 38(a) or 38(b).

Alternatively, a pair of optical amplifiers 26A
and 26B are additionally provided at both of a preceding
stage and a next stage to each group (optical dispersion
20 compensator unit 25) of optical dispersion compensator
units 25A and 25B as shown in FIG. 39.

Where only one amplifier is provided, not only a
high gain sufficient to compensate for both of the
transmission line loss and the optical loss at the
25 optical dispersion compensator unit 25 is required, but
where the optical dispersion compensator unit 25 having
a high optical loss is located at a preceding stage to

1 the optical amplifier 26, this makes a cause to degrade
the NF significantly. This must be eliminated
particularly where an optical dispersion compensator
unit 25 is inserted in a 1R repeater in an optical
5 amplifier multi-repeater system.

Therefore, where such a construction as shown in
FIG. 39 wherein the two optical amplifiers 26A and 26B
are provided on the opposite front and rear ends of the
optical dispersion compensator unit 25 is employed, the
10 NF of the entire 1R repeater can be reduced low by
minimizing the NF of the optical amplifier at the
preceding stage, and a sufficient gain can be assured by
means of the two stages of optical amplifiers 26A and
26B.

15 Incorporation of such an optical dispersion
compensator unit 25 as described above into the
transmitter 21, each of the repeaters 22 or the receiver
23 is performed, for example, in the following manner.
A space sufficient to allow insertion of an optical
20 dispersion compensator unit 25 therein is assured in
advance in each of the transmitter 21, the repeaters 22
and the receiver 23, and after installation of the
system, optimum optical dispersion compensator units 25
conforming to the transmission line (optical
25 transmission system 20) are additionally inserted into
the spaces to incorporate the optical dispersion
compensators 25 into the optical transmission system 20.

1 Meanwhile, electronic parts and optical parts in
an optical transmission apparatus are generally mounted
on a printed circuit board (a printed circuit board on
which electronic parts and/or optical parts are mounted
5 in this manner is called package), and such package in
most cases has a structure which allows mounting and
dismounting onto and from an apparatus support frame.

 Thus, a dispersion compensation package having
optical dispersion compensator units mounted thereon may
10 be provided so that it may be mounted and dismounted
onto and from an apparatus supporting frame. For
example, a package obtained by packaging the optical
dispersion compensator unit 25 shown in FIG. 39 is shown
in FIG. 40. Referring to FIG. 40, an optical dispersion
15 compensator unit 25 including a pair of front and rear
optical amplifiers 26A and 26B and three optical
dispersion compensator units 25A and 25B of two
different types is mounted on a printed circuit board 27
to constitute a dispersion compensation package 28. It
20 is to be noted that each of the optical dispersion
compensator units 25A and 25B is constituted from a
dispersion compensation fiber (optical fiber 2) wound by
a predetermined length around a small bobbin located on
the printed circuit board 27.

25 Where such a dispersion compensation package 28
as described above is employed, optical dispersion
compensator units 25 can be replaced or incorporated

1 readily in units of a package. Consequently, the
dispersion compensation amount can be varied readily.

0. Fifteenth Embodiment

5 Subsequently, an optical dispersion compensation
method of a fifteenth preferred embodiment of the
present invention will be described. FIG. 41 shows, in
block diagram, an optical dispersion compensation
apparatus to which the optical dispersion compensation
method is applied, and FIGS. 42 and 43 show different
10 modifications to the optical dispersion compensation
apparatus. It is to be noted that like reference
characters denote like elements to those described
hereinabove, and overlapping description thereof is
omitted herein to avoid redundancy.

15 In the fifteenth embodiment, such an optical
dispersion compensator unit 32 is built in each of the
transmitter 21, the repeaters 22 and the receiver 23
which constitute the optical transmission system 20.

20 Referring to FIG. 41, the optical dispersion
compensator unit 32 includes three stages of optical
dispersion compensator units 25A to 25D of a plurality
of different kinds (four kinds having dispersion amounts
B1 to B4 in the arrangement shown in FIG. 41) having
different dispersion amounts having different positive
25 and negative signs, and switches (switching means) 29A
to 29C connected to the three stages of optical
dispersion compensator units 25A to 25D for switching

1 the selective combination of the optical dispersion
compensator units 25A to 25D. When each of the switches
29A to 29C is operated for switching, one of the four
kinds of optical dispersion compensator units 25A to 25D
5 of the corresponding stage is selected, and
consequently, by operation of the switches 29A to 29C, a
suitable combination of three optical dispersion
compensator units 25A to 25D can be selectively
incorporated into the optical transmission system 20.

10 It is to be noted that each of the switches 29A
to 29C may be means for wiring any of the optical
dispersion compensator units 25A to 25D by means of an
optical fiber (mechanical connection or mechanical
switch) or means for selecting a connection route by
15 means of an optical switch. The optical switch may be
an optical waveguide switch or a spatial change-over
switch.

Further, as means for changing over each of the
switches 29A to 29C, means for modifying the wiring
20 system of the optical fiber or switching the optical
switch on/off simply by a personal operation from the
outside or means for automatically performing such
changing over operation in response to an electric or
optical control signal from the outside may be applied.

25 Subsequently, detailed adaptations of a
switching operation of the switches 29A to 29C in
response to a control signal from the outside to select

1 a suitable combination of three optical dispersion
compensator units 25A to 25D will be described with
reference to FIGS. 42 and 43

5 In means for automatically performing a
switching operation in response to a control signal, a
control signal may be sent from a transmitter-receiver
terminal office to each repeater 22, or as in the
adaptation illustrated in FIG. 42, a control signal may
be sent from a center office 30, which controls the
10 entire system in a concentrated manner, to each of the
switches 29A to 29C of the optical dispersion
compensator unit 32 which are provided in each of the
transmitter 21, the repeaters 22 and the receiver 23.

Meanwhile, in the adaptation illustrated in FIG.
15 43, the receiver 23 has a function of outputting a
switching control signal to each of the switches 29A to
29C of the optical dispersion compensator unit 32
provided in each of the transmitter 21 and the repeaters
22, and includes transmission characteristic measurement
20 means 31 for measuring transmission characteristics
(error rate, waveform and so forth) of the optical
transmission system 20.

Thus, the switches 29A to 29C are operated in
response to control signals from the receiver 23 to
25 successively change the selective combination of the
optical dispersion compensator units 25A to 25D of the
optical dispersion compensator units 32 while the

1 transmission characteristics of the optical transmission
system 20 are measured by the transmission
characteristic measurement means 31 to determine a
combination of optical dispersion compensator units 25A
5 to 25D which provides optimum transmission
characteristics of the optical transmission system 20.
and then, the switches 29A to 29C are operated in
response to control signals from the receiver 23 to
change over the combination of optical dispersion
10 compensator units 25A to 25D to the thus determined
combination which provides the optimum transmission
characteristics to the optical transmission system 20.

In this manner, with the optical dispersion
compensation method of the fifteenth embodiment, since a
15 plurality of kinds of optical dispersion compensator
units 25A to 25D are built in advance in each of the
transmitter 21, the repeaters 22 and the receiver 23 of
the optical transmission system 20 in such a connected
condition that the combination of optical dispersion
20 compensator units 25A to 25D can be selectively switched
by way of the switches 29A to 29C, a suitable
combination of optical dispersion compensator units 25A
to 25D is selected from within the optical dispersion
compensator units 25A to 25D by operating the switches
25 29A to 29C. Particularly where the construction shown
in FIG. 43 is employed, the combination of optical
dispersion compensator units 25A to 25D can be

1 automatically changed over to a combination which
provides optimum transmission characteristics to the
optical transmission system 20

5 It is to be noted that, while, in the embodiment
described above, description has been given of the case
wherein an optical dispersion compensator unit 32 is
built in each of the transmitter 21, the repeaters 22
and the receiver 23 which constitute the optical
transmission system 20, advantages similar to those
10 described above can be obtained where such optical
dispersion compensator unit 32 is built in at least one
of the transmitter 21, the repeaters 22 and the receiver
23.

15 The present invention is not limited to the
specifically described embodiment, and variations and
modifications may be made without departing from the
scope of the present invention.

20

25

1 WHAT IS CLAIMED IS:

1 In an optical wavelength multiplex
5 transmission method for multiplexing signal light waves
of a plurality of channels having different wavelengths
and transmitting the multiplexed signal light using an
optical fiber, the improvement wherein:
a four wave mixing suppressing guard band of a
10 predetermined bandwidth including a zero-dispersion
wavelength of said optical fiber is set; and
the signal light waves of the plurality of
channels to be multiplexed are arranged on one of a
shorter wavelength side and a longer wavelength side
15 outside the guard band.

2. In an optical wavelength multiplex
transmission method for multiplexing signal light waves
20 of a plurality of channels having different wavelengths
and transmitting the multiplexed signal light using an
optical fiber, the improvement wherein:
a four wave mixing suppressing guard band of a
predetermined bandwidth including a zero-dispersion
25 wavelength of said optical fiber is set; and
the signal light waves of the plurality of
channels to be multiplexed are arranged on the opposite

1 sides of a shorter wavelength side and a longer
wavelength side outside the guard band.

5 3. An optical wavelength multiplex transmission
method as claimed in claim 2, wherein the bandwidths of
the guard bands are set in an asymmetrical relationship
on the shorter wavelength side and the longer wavelength
side with respect to the zero-dispersion wavelength of
10 said optical fiber.

15 4. An optical wavelength multiplex transmission
method as claimed in claim 3, wherein the channel
spacings between adjacent ones of the signal light waves
of the plurality of channels are set different on the
shorter wavelength side and the longer wavelength side
outside the guard band.

20 5. An optical wavelength multiplex transmission
method as claimed in claim 3, wherein the channel
spacings between adjacent ones of the signal light waves
of the plurality of channels on each of the shorter
25 wavelength side and the longer wavelength side outside
the guard band are set to an integral number of times a
constant.

1 6. An optical wavelength multiplex transmission
method as claimed in claim 5. wherein the channel
spacings between the channels of the signal light waves
of the plurality of channels on the opposite sides of
5 the guard band are set to the integral number of times
the constant.

10 7. An optical wavelength multiplex transmission
method as claimed in claim 3. wherein the signal light
waves of the channels are arranged such that the signal
light waves of no pair or only one pair of ones of the
channels have dispersion values which have an equal
absolute value.

15 8. In an optical wavelength multiplex
transmission method for multiplexing signal light waves
of a plurality of channels having different wavelengths
and transmitting the multiplexed signal light using an
20 optical fiber, the improvement wherein:

taking a zero-dispersion wavelength λ_0 of said
optical fiber and a zero-dispersion wavelength deviation
range $\pm\Delta\lambda_0$ of said optical fiber in its longitudinal
25 direction into consideration, the signal light waves of
the plurality of channels to be multiplexed are arranged
on a shorter wavelength side than a shorter wavelength

1 end $\lambda_0 - \Delta\lambda_0$ of the zero-dispersion wavelength deviation
range of said optical fiber.

5 9. An optical wavelength multiplex transmission
method as claimed in claim 8, wherein a four wave mixing
suppressing guard band $\Delta\lambda_g$ is provided on the shorter
wavelength side than the shorter wavelength end $\lambda_0 - \Delta\lambda_0$
10 of the zero-dispersion wavelength deviation range of
said optical fiber, and the signal light waves of the
plurality of channels are arranged on a shorter
wavelength side than a wavelength $\lambda_0 - \Delta\lambda_0 - \Delta\lambda_g$.

15 10. In an optical wavelength multiplex
transmission method for multiplexing signal light waves
of a plurality of channels having different wavelengths
and transmitting the multiplexed signal light using an
optical fiber, the improvement wherein:

20 taking a zero-dispersion wavelength λ_0 of said
optical fiber and a zero-dispersion wavelength deviation
range $\pm\Delta\lambda_0$ of said optical fiber in its longitudinal
direction into consideration, the signal light waves of
the plurality of channels to be multiplexed are arranged
25 on a longer wavelength side than a longer wavelength end
 $\lambda_0 + \Delta\lambda_0$ of the zero-dispersion wavelength deviation
range of said optical fiber.

1 11. An optical wavelength multiplex
transmission method as claimed in claim 10, wherein a
four wave mixing suppressing guard band $\Delta\lambda_g$ is provided
on the longer wavelength side than the longer wavelength
5 end $\lambda_0 + \Delta\lambda_0$ of the zero-dispersion wavelength deviation
range of said optical fiber, and the signal light waves
of the plurality of channels are arranged on a longer
wavelength side than a wavelength $\lambda_0 + \Delta\lambda_0 + \Delta\lambda_g$.

10 12. An optical wavelength multiplex
transmission method as claimed in claim 9, wherein the
signal light waves of the plurality of channels are
arranged within a transmissible band defined by an
15 allowable dispersion value determined from a synergetic
effect of self phase modulation and group velocity
dispersion in said optical fiber.

20 13. An optical wavelength multiplex
transmission method as claimed in claim 11, wherein the
signal light waves of the plurality of channels are
arranged within a transmissible band defined by an
allowable dispersion value determined from a synergetic
25 effect of self phase modulation and group velocity
dispersion in said optical fiber.

1 14. An optical wavelength multiplex
transmission method as claimed in claim 12, wherein the
signal light waves of the plurality of channels are
arranged outside the transmissible band defined by the
5 allowable dispersion value determined from the
synergetic effect of self phase modulation and group
velocity dispersion in said optical fiber, and the zero
dispersion wavelength λ_0 of said optical fiber is
apparently shifted using an optical dispersion
10 compensator to apparently arrange the signal light waves
of the plurality of channels into the transmissible
band.

15 15. An optical wavelength multiplex
transmission method as claimed in claim 13, wherein the
signal light waves of the plurality of channels are
arranged outside the transmissible band defined by the
allowable dispersion value determined from the
20 synergetic effect of self phase modulation and group
velocity dispersion in said optical fiber, and the zero
dispersion wavelength λ_0 of said optical fiber is
apparently shifted using an optical dispersion
compensator to apparently arrange the signal light waves
25 of the plurality of channels into the transmissible
band.

1 16. An optical wavelength multiplex
transmission method as claimed in claim 12. wherein,
taking a dispersion compensation amount deviation range
 $\pm\delta\lambda_{DC}$ of said optical dispersion compensator into
5 consideration, a band $\Delta\lambda_{WDM}$ within which the signal
light waves of the plurality of channels are to be
arranged is set expanding the same by the dispersion
compensation amount deviation range $\delta\lambda_{DC}$ on the opposite
sides of the longer wavelength side and the shorter
10 wavelength side.

 17. An optical wavelength multiplex
transmission method as claimed in claim 13. wherein,
15 taking a dispersion compensation amount deviation range
 $\pm\delta\lambda_{DC}$ of said optical dispersion compensator into
consideration, a band $\Delta\lambda_{WDM}$ within which the signal
light waves of the plurality of channels are to be
arranged is set expanding the same by the dispersion
20 compensation amount deviation range $\delta\lambda_{DC}$ on the opposite
sides of the longer wavelength side and the shorter
wavelength side.

25 18. An optical wavelength multiplex
transmission method as claimed in claim 14. wherein,
taking a dispersion compensation amount deviation range

1 $\pm\delta\lambda_{DC}$ of said optical dispersion compensator into
consideration, a band $\Delta\lambda_{WDM}$ within which the signal
light waves of the plurality of channels are to be
arranged is set expanding the same by the dispersion
5 compensation amount deviation range $\delta\lambda_{DC}$ on the opposite
sides of the longer wavelength side and the shorter
wavelength side.

10 19. An optical wavelength multiplex
transmission method as claimed in claim 15, wherein,
taking a dispersion compensation amount deviation range
 $\pm\delta\lambda_{DC}$ of said optical dispersion compensator into
consideration, a band $\Delta\lambda_{WDM}$ within which the signal
15 light waves of the plurality of channels are to be
arranged is set expanding the same by the dispersion
compensation amount deviation range $\delta\lambda_{DC}$ on the opposite
sides of the longer wavelength side and the shorter
wavelength side.

20

20. An optical wavelength multiplex
transmission method as claimed in claim 12, wherein the
signal light waves of the plurality of channels are
25 arranged in a gain band of an optical amplifier
connected to said optical fiber.

1 21. An optical wavelength multiplex
transmission method as claimed in claim 13, wherein the
signal light waves of the plurality of channels are
arranged in a gain band of an optical amplifier
5 connected to said optical fiber.

22. An optical wavelength multiplex
transmission method as claimed in claim 14, wherein the
10 signal light waves of the plurality of channels are
arranged in a gain band of an optical amplifier
connected to said optical fiber.

15 23. An optical wavelength multiplex
transmission method as claimed in claim 15, wherein the
signal light waves of the plurality of channels are
arranged in a gain band of an optical amplifier
connected to said optical fiber.

20

24. An optical wavelength multiplex
transmission method as claimed in claim 16, wherein the
signal light waves of the plurality of channels are
25 arranged in a gain band of an optical amplifier
connected to said optical fiber.

1 25 An optical wavelength multiplex
transmission method as claimed in claim 17. wherein the
signal light waves of the plurality of channels are
arranged in a gain band of an optical amplifier
5 connected to said optical fiber.

 26. An optical wavelength multiplex
transmission method as claimed in claim 18. wherein the
10 signal light waves of the plurality of channels are
arranged in a gain band of an optical amplifier
connected to said optical fiber.

15 27. An optical wavelength multiplex
transmission method as claimed in claim 19. wherein the
signal light waves of the plurality of channels are
arranged in a gain band of an optical amplifier
connected to said optical fiber.

20

 28. An optical wavelength multiplex
transmission method as claimed in claim 12. wherein a
band $\Delta\lambda_{\text{opt}}$ within which the signal light waves of the
25 plurality of channels are to be arranged is set
expanding the same in accordance with optical wavelength
variations of the signal light waves of the plurality of

1 channels

29. An optical wavelength multiplex
5 transmission method as claimed in claim 13, wherein a
band $\Delta\lambda_{\text{WDM}}$ within which the signal light waves of the
plurality of channels are to be arranged is set
expanding the same in accordance with optical wavelength
variations of the signal light waves of the plurality of
10 channels.

30. An optical wavelength multiplex
transmission method as claimed in claim 14, wherein a
15 band $\Delta\lambda_{\text{WDM}}$ within which the signal light waves of the
plurality of channels are to be arranged is set
expanding the same in accordance with optical wavelength
variations of the signal light waves of the plurality of
channels.

20

31. An optical wavelength multiplex
transmission method as claimed in claim 15, wherein a
band $\Delta\lambda_{\text{WDM}}$ within which the signal light waves of the
25 plurality of channels are to be arranged is set
expanding the same in accordance with optical wavelength
variations of the signal light waves of the plurality of

1 channels.

32. An optical wavelength multiplex
5 transmission method as claimed in claim 16, wherein a
band $\Delta\lambda_{\text{WDM}}$ within which the signal light waves of the
plurality of channels are to be arranged is set
expanding the same in accordance with optical wavelength
variations of the signal light waves of the plurality of
10 channels.

33. An optical wavelength multiplex
transmission method as claimed in claim 17, wherein a
15 band $\Delta\lambda_{\text{WDM}}$ within which the signal light waves of the
plurality of channels are to be arranged is set
expanding the same in accordance with optical wavelength
variations of the signal light waves of the plurality of
channels.

20

34. An optical wavelength multiplex
transmission method as claimed in claim 18, wherein a
band $\Delta\lambda_{\text{WDM}}$ within which the signal light waves of the
25 plurality of channels are to be arranged is set
expanding the same in accordance with optical wavelength
variations of the signal light waves of the plurality of

1 channels

35. An optical wavelength multiplex
5 transmission method as claimed in claim 19, wherein a
band $\Delta\lambda_{\text{WDM}}$ within which the signal light waves of the
plurality of channels are to be arranged is set
expanding the same in accordance with optical wavelength
variations of the signal light waves of the plurality of
10 channels.

36. An optical wavelength multiplex
transmission method as claimed in claim 20, wherein a
15 band $\Delta\lambda_{\text{WDM}}$ within which the signal light waves of the
plurality of channels are to be arranged is set
expanding the same in accordance with optical wavelength
variations of the signal light waves of the plurality of
channels.

20

37. An optical wavelength multiplex
transmission method as claimed in claim 21, wherein a
band $\Delta\lambda_{\text{WDM}}$ within which the signal light waves of the
25 plurality of channels are to be arranged is set
expanding the same in accordance with optical wavelength
variations of the signal light waves of the plurality of

1 channels.

38. An optical wavelength multiplex
5 transmission method as claimed in claim 22, wherein a
band $\Delta\lambda_{\text{WDM}}$ within which the signal light waves of the
plurality of channels are to be arranged is set
expanding the same in accordance with optical wavelength
variations of the signal light waves of the plurality of
10 channels.

39. An optical wavelength multiplex
transmission method as claimed in claim 23, wherein a
15 band $\Delta\lambda_{\text{WDM}}$ within which the signal light waves of the
plurality of channels are to be arranged is set
expanding the same in accordance with optical wavelength
variations of the signal light waves of the plurality of
channels.

20

40. An optical wavelength multiplex
transmission method as claimed in claim 24, wherein a
band $\Delta\lambda_{\text{WDM}}$ within which the signal light waves of the
25 plurality of channels are to be arranged is set
expanding the same in accordance with optical wavelength
variations of the signal light waves of the plurality of

channels

41. An optical wavelength multiplex transmission method as claimed in claim 25, wherein a band $\Delta\lambda_{\text{WDM}}$ within which the signal light waves of the plurality of channels are to be arranged is set expanding the same in accordance with optical wavelength variations of the signal light waves of the plurality of channels

42. An optical wavelength multiplex transmission method as claimed in claim 26, wherein a band $\Delta\lambda_{\text{WDM}}$ within which the signal light waves of the plurality of channels are to be arranged is set expanding the same in accordance with optical wavelength variations of the signal light waves of the plurality of channels.

43. An optical wavelength multiplex transmission method as claimed in claim 27, wherein a band $\Delta\lambda_{\text{WDM}}$ within which the signal light waves of the plurality of channels are to be arranged is set expanding the same in accordance with optical wavelength variations of the signal light waves of the plurality of

1 channels.

44. An optical dispersion compensation method
5 for compensating for a dispersion amount of an optical
transmission system which includes a transmitter, a
repeater and a receiver and transmits signal light from
said transmitter to said receiver by way of said
repeater, comprising the steps of:

10 preparing in advance two kinds of optical
dispersion compensator units having dispersion amounts
having different positive and negative signs:

inserting the two kinds of optical dispersion
compensator units separately into said optical
15 transmission system: and

selecting one of the two kinds of optical
dispersion compensator units which provides a better
transmission characteristic to said optical transmission
system and incorporating the selected optical dispersion
20 compensator unit into said optical transmission system.

45. An optical dispersion compensation method
for compensating for a dispersion amount of an optical
25 transmission system which includes a transmitter, a
repeater and a receiver and transmits signal light from
said transmitter to said receiver by way of said

1 repeater, comprising the steps of:

preparing in advance two kinds of optical dispersion compensator units having dispersion amounts having different positive and negative signs:

5 measuring a dispersion amount of said optical transmission system; and

selecting one of the two kinds of optical dispersion compensator units which has a dispersion amount whose sign is opposite to that of a measured
10 dispersion amount and incorporating the selected optical dispersion compensator unit into said optical transmission system.

15 46. An optical dispersion compensation method for compensating for a dispersion amount of an optical transmission system which includes a transmitter, a repeater and a receiver and transmits signal light from said transmitter to said receiver by way of said
20 repeater, comprising the steps of:

preparing in advance a plurality of kinds of optical dispersion compensator units having different dispersion amounts having different positive and negative signs:

25 selectively inserting the plurality of kinds of optical dispersion compensator units into said optical transmission system changing the installation number and

1 the combination of the optical dispersion compensator
units: and

selecting an installation number and a
combination of the optical dispersion compensator units
5 from within the plurality of kinds of optical dispersion
compensator units which provide a good transmission
characteristic to said optical transmission system and
incorporating the optical dispersion compensator units
of the selected installation number and combination into
10 said optical transmission system.

47. An optical dispersion compensation method
for compensating for a dispersion amount of an optical
15 transmission system which includes a transmitter, a
repeater and a receiver and transmits signal light from
said transmitter to said receiver by way of said
repeater, comprising the steps of:

preparing in advance a plurality of kinds of
20 optical dispersion compensator units having different
dispersion amounts having different positive and
negative signs:

measuring a dispersion amount of said optical
transmission system: and

25 selecting an installation number and a
combination of the optical dispersion compensator units
from within the plurality of kinds of optical dispersion

1 compensator units, with which dispersion values of the
signal light waves fall within a transmissible
dispersion value range, in accordance with a measured
dispersion value and incorporating the optical
5 dispersion compensator units of the selected
installation number and combination into said optical
transmission system.

10 48. An optical dispersion compensation method
as claimed in claim 44, wherein the optical dispersion
compensator units are additionally incorporated into at
least one of said transmitter, said repeater and said
receiver of said optical transmission system to
15 incorporate the optical dispersion compensator units
into said optical transmission system.

20 49. An optical dispersion compensation method
as claimed in claim 45, wherein the optical dispersion
compensator units are additionally incorporated into at
least one of said transmitter, said repeater and said
receiver of said optical transmission system to
incorporate the optical dispersion compensator units
25 into said optical transmission system.

1 50 An optical dispersion compensation method
as claimed in claim 46, wherein the optical dispersion
compensator units are additionally incorporated into at
least one of said transmitter, said repeater and said
5 receiver of said optical transmission system to
incorporate the optical dispersion compensator units
into said optical transmission system.

10 51. An optical dispersion compensation method
as claimed in claim 47, wherein the optical dispersion
compensator units are additionally incorporated into at
least one of said transmitter, said repeater and said
receiver of said optical transmission system to
15 incorporate the optical dispersion compensator units
into said optical transmission system.

20 52. An optical dispersion compensation method
as claimed in claim 50, wherein, when said optical
transmission system performs optical wavelength
multiplex transmission to multiplex and transmit signal
light waves of a plurality of channels having different
wavelengths, the signal light waves are demultiplexed
25 for each one wave by wavelength demultiplexing and the
optical dispersion compensator units are provided for
the individual channels of the signal light waves of the

1 wavelengths in said optical transmission system.

53. An optical dispersion compensation method
5 as claimed in claim 51. wherein, when said optical
transmission system performs optical wavelength
multiplex transmission to multiplex and transmit signal
light waves of a plurality of channels having different
wavelengths, the signal light waves are demultiplexed
10 for each one wave by wavelength demultiplexing and the
optical dispersion compensator units are provided for
the individual channels of the signal light waves of the
wavelengths in said optical transmission system.

15
54. An optical dispersion compensation method
as claimed in claim 50. wherein, when said optical
transmission system performs optical wavelength
multiplex transmission to multiplex and transmit signal
20 light waves of a plurality of channels having different
wavelengths, the signal light waves are demultiplexed
for each plurality of waves and the optical dispersion
compensator units are provided for the individual
channel groups each including a plurality of signal
25 light waves in said optical transmission system.

1 55. An optical dispersion compensation method
as claimed in claim 51. wherein, when said optical
transmission system performs optical wavelength
multiplex transmission to multiplex and transmit signal
5 light waves of a plurality of channels having different
wavelengths, the signal light waves are demultiplexed
for each plurality of waves and the optical dispersion
compensator units are provided for the individual
channel groups each including a plurality of signal
10 light waves in said optical transmission system.

 56. An optical dispersion compensation method
as claimed in claim 50. wherein, when said optical
15 transmission system performs optical wavelength
multiplex transmission to multiplex and transmit signal
light waves of a plurality of channels having different
wavelengths, the optical dispersion compensator units
are provided for all of the signal light waves of the
20 plurality of channels in said optical transmission
system.

 57. An optical dispersion compensation method
25 as claimed in claim 51. wherein, when said optical
transmission system performs optical wavelength
multiplex transmission to multiplex and transmit signal

1 light waves of a plurality of channels having different
wavelengths, the optical dispersion compensator units
are provided for all of the signal light waves of the
plurality of channels in said optical transmission
5 system.

58. An optical dispersion compensation method
as claimed in claim 50, wherein each of the optical
10 dispersion compensator units is additionally provided
with an optical amplifier for compensating for an
optical loss of the optical dispersion compensator unit.

59. An optical dispersion compensation method
as claimed in claim 51, wherein each of the optical
15 dispersion compensator units is additionally provided
with an optical amplifier for compensating for an
optical loss of the optical dispersion compensator unit.

20

60. An optical dispersion compensation method
as claimed in claim 52, wherein each of the optical
dispersion compensator units is additionally provided
25 with an optical amplifier for compensating for an
optical loss of the optical dispersion compensator unit.

1 61. An optical dispersion compensation method
as claimed in claim 53. wherein each of the optical
dispersion compensator units is additionally provided
with an optical amplifier for compensating for an
5 optical loss of the optical dispersion compensator unit.

10 62. An optical dispersion compensation method
as claimed in claim 54. wherein each of the optical
dispersion compensator units is additionally provided
with an optical amplifier for compensating for an
optical loss of the optical dispersion compensator unit.

15 63. An optical dispersion compensation method
as claimed in claim 55. wherein each of the optical
dispersion compensator units is additionally provided
with an optical amplifier for compensating for an
optical loss of the optical dispersion compensator unit.

20

25 64. An optical dispersion compensation method
as claimed in claim 56. wherein each of the optical
dispersion compensator units is additionally provided
with an optical amplifier for compensating for an
optical loss of the optical dispersion compensator unit

1 65. An optical dispersion compensation method
as claimed in claim 57, wherein each of the optical
dispersion compensator units is additionally provided
with an optical amplifier for compensating for an
5 optical loss of the optical dispersion compensator unit.

 66. An optical dispersion compensation method
as claimed in claim 58, wherein a pair of optical
10 amplifiers are additionally provided at a preceding
stage and a next stage to each of the optical dispersion
compensator units.

15 67. An optical dispersion compensation method
as claimed in claim 59, wherein a pair of optical
amplifiers are additionally provided at a preceding
stage and a next stage to each of the optical dispersion
compensator units.

20

 68. An optical dispersion compensation method
as claimed in claim 60, wherein a pair of optical
amplifiers are additionally provided at a preceding
25 stage and a next stage to each of the optical dispersion
compensator units.

1 69. An optical dispersion compensation method
as claimed in claim 61, wherein a pair of optical
amplifiers are additionally provided at a preceding
stage and a next stage to each of the optical dispersion
5 compensator units.

70 An optical dispersion compensation method
as claimed in claim 62, wherein a pair of optical
10 amplifiers are additionally provided at a preceding
stage and a next stage to each of the optical dispersion
compensator units.

15 71. An optical dispersion compensation method
as claimed in claim 63, wherein a pair of optical
amplifiers are additionally provided at a preceding
stage and a next stage to each of the optical dispersion
compensator units.

20

72. An optical dispersion compensation method
as claimed in claim 64, wherein a pair of optical
amplifiers are additionally provided at a preceding
25 stage and a next stage to each of the optical dispersion
compensator units.

1 73. An optical dispersion compensation method
as claimed in claim 65, wherein a pair of optical
amplifiers are additionally provided at a preceding
stage and a next stage to each of the optical dispersion
5 compensator units.

10 74. An optical dispersion compensation method
as claimed in claim 58, wherein the optical dispersion
compensator units are constructed as a package wherein
they are mounted on a circuit board so that the optical
dispersion compensator units are replaced or
incorporated in units of a package.

15 75. An optical dispersion compensation method
as claimed in claim 59, wherein the optical dispersion
compensator units are constructed as a package wherein
they are mounted on a circuit board so that the optical
20 dispersion compensator units are replaced or
incorporated in units of a package.

25 76. An optical dispersion compensation method
as claimed in claim 60, wherein the optical dispersion
compensator units are constructed as a package wherein
they are mounted on a circuit board so that the optical

1 dispersion compensator units are replaced or
incorporated in units of a package.

5 77. An optical dispersion compensation method
as claimed in claim 61. wherein the optical dispersion
compensator units are constructed as a package wherein
they are mounted on a circuit board so that the optical
dispersion compensator units are replaced or
10 incorporated in units of a package.

78. An optical dispersion compensation method
as claimed in claim 62. wherein the optical dispersion
15 compensator units are constructed as a package wherein
they are mounted on a circuit board so that the optical
dispersion compensator units are replaced or
incorporated in units of a package.

20 79. An optical dispersion compensation method
as claimed in claim 63. wherein the optical dispersion
compensator units are constructed as a package wherein
they are mounted on a circuit board so that the optical
25 dispersion compensator units are replaced or
incorporated in units of a package.

1 80. An optical dispersion compensation method
as claimed in claim 64. wherein the optical dispersion
compensator units are constructed as a package wherein
they are mounted on a circuit board so that the optical
5 dispersion compensator units are replaced or
incorporated in units of a package.

10 81. An optical dispersion compensation method
as claimed in claim 65. wherein the optical dispersion
compensator units are constructed as a package wherein
they are mounted on a circuit board so that the optical
dispersion compensator units are replaced or
15 incorporated in units of a package.

15 82. An optical dispersion compensation method
for compensating for a dispersion amount of an optical
transmission system which includes a transmitter, a
20 repeater and a receiver and transmits signal light from
said transmitter to said receiver by way of said
repeater, comprising the steps of:

incorporating, in advance into at least one of
said transmitter, said repeater and said receiver of
25 said optical transmission system, a plurality of kinds
of optical dispersion compensator units having different
dispersion amounts having different positive and

1 negative signs in such a connected condition as to allow
switching of a selective combination of the optical
dispersion compensator units by means of switching
means; and

5 operating said switching means to select a
suitable combination of the optical dispersion
compensator units from within the plurality of types of
optical dispersion compensator units and incorporating
the optical dispersion compensator units of the selected
10 combination into said optical transmission system.

83. An optical dispersion compensation method
as claimed in claim 82, wherein said switching means is
15 operated in response to a control signal from the
outside.

84. An optical dispersion compensation method
20 as claimed in claim 83, wherein said switching means is
operated in response to a control signal from said
receiver to switch the combination of the optical
dispersion compensator units while a transmission
characteristic of said optical transmission system is
25 measured simultaneously by said receiver to determine a
combination of the optical dispersion compensator units
which provides an optimum transmission characteristic to

1 said optical transmission system, and said switching
means is operated in response to another control signal
from said receiver to switch the combination of the
optical dispersion compensator units to the determined
5 combination which provides the optimum transmission
characteristic to said optical transmission system.

85. An optical dispersion compensation method
10 as claimed in claim 82, wherein said switching means
includes a mechanical switch.

86. An optical dispersion compensation method
15 as claimed in claim 83, wherein said switching means
includes a mechanical switch.

87. An optical dispersion compensation method
20 as claimed in claim 84, wherein said switching means
includes a mechanical switch.

88. An optical dispersion compensation method
25 as claimed in claim 82, wherein said switching means
includes an optical switch.

1 89. An optical dispersion compensation method
as claimed in claim 83. wherein said switching means
includes an optical switch

5

90. An optical dispersion compensation method as claimed in claim 84, wherein said switching means includes an optical switch.

10

15

20

25

FIG. 1

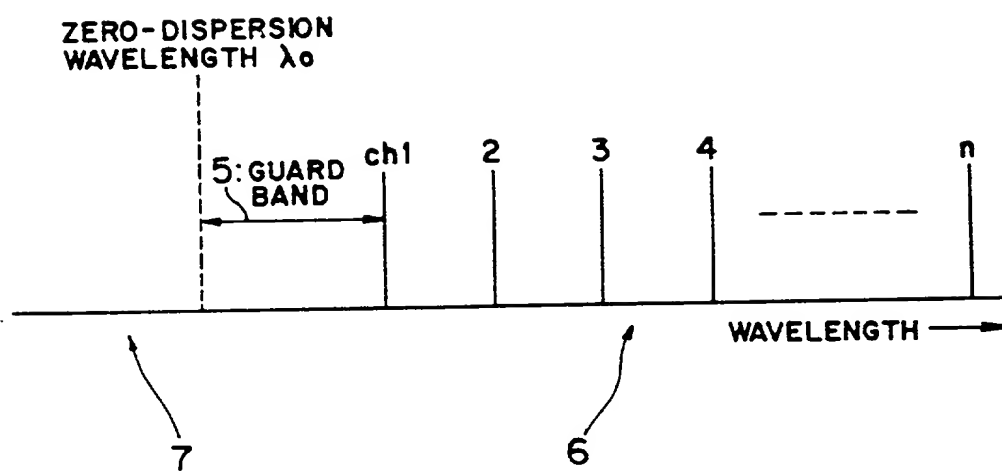


FIG. 3

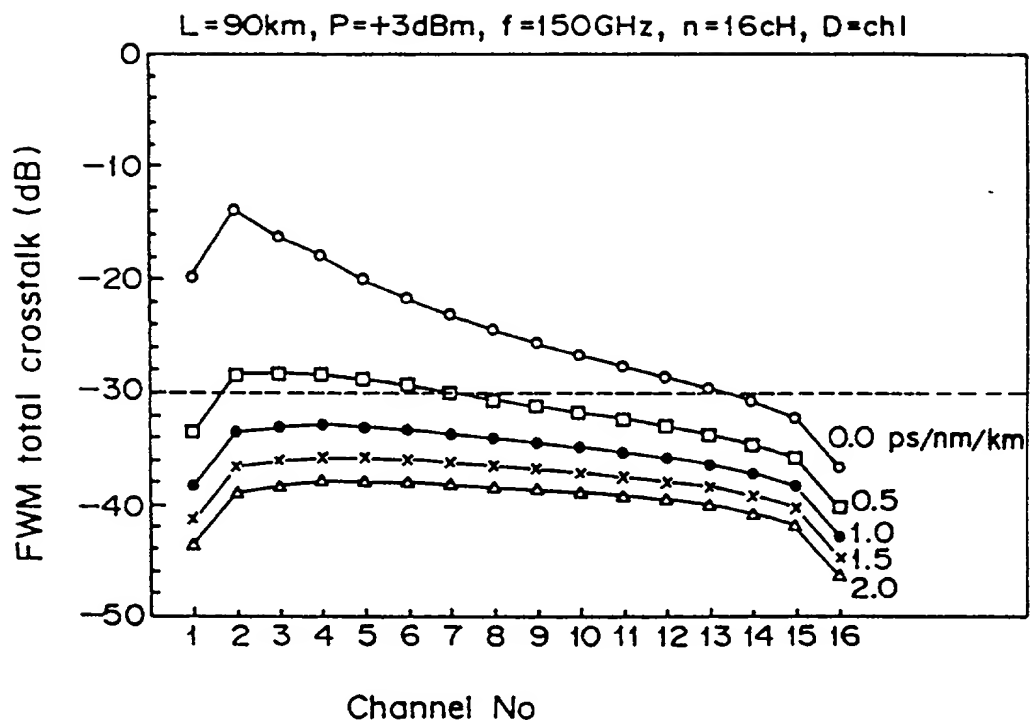


FIG. 4

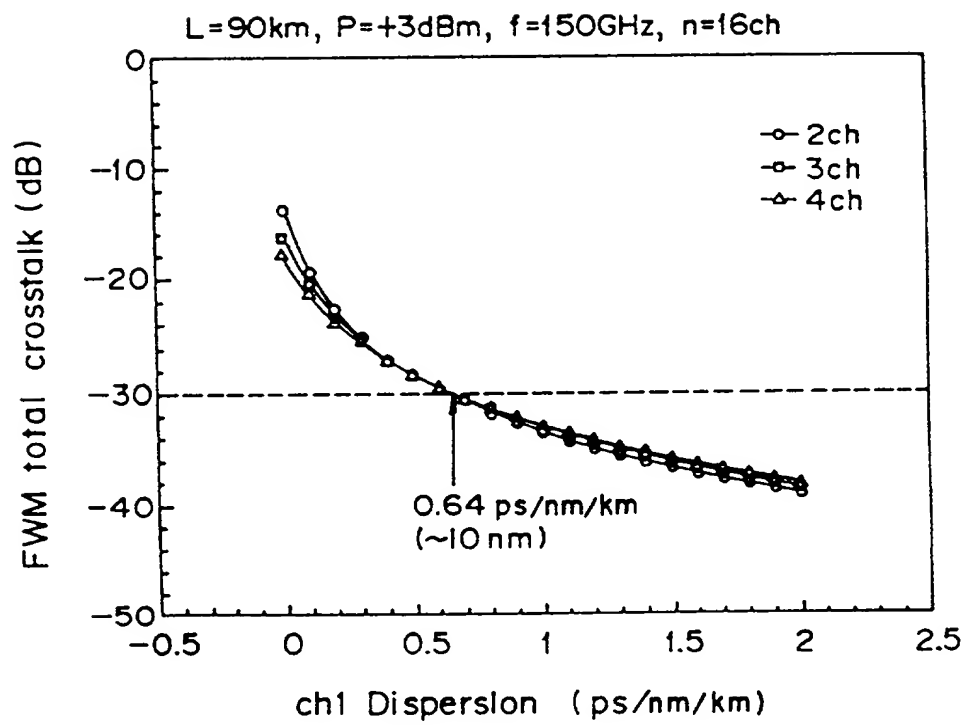


FIG. 5

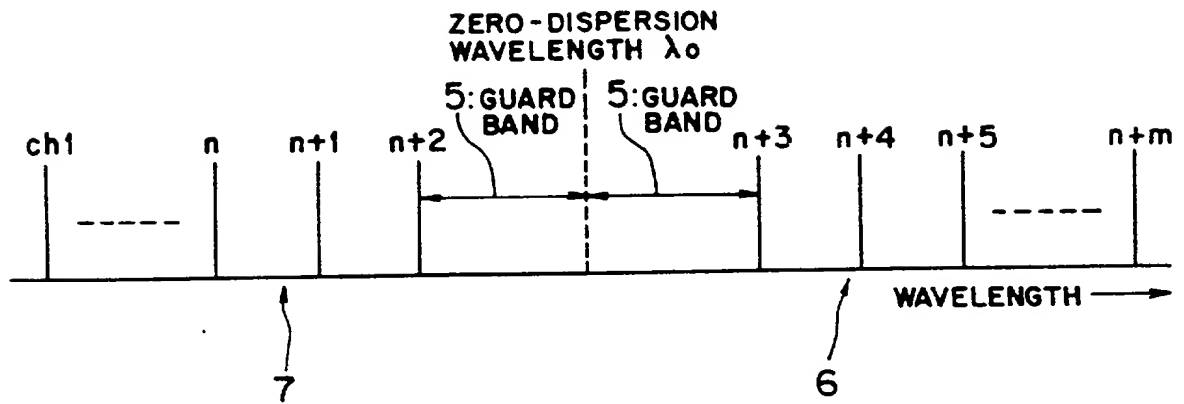


FIG. 6

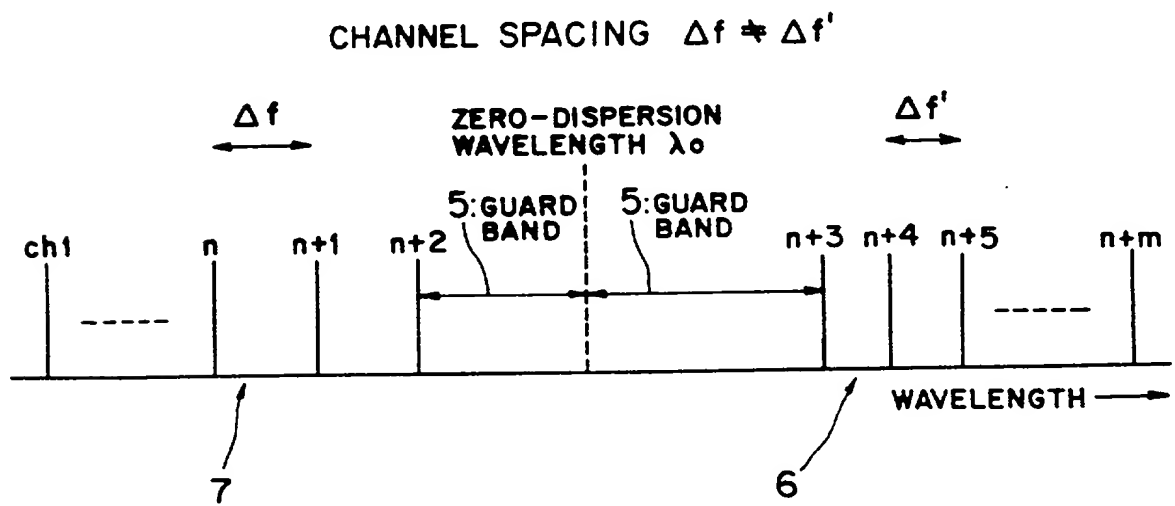


FIG. 7

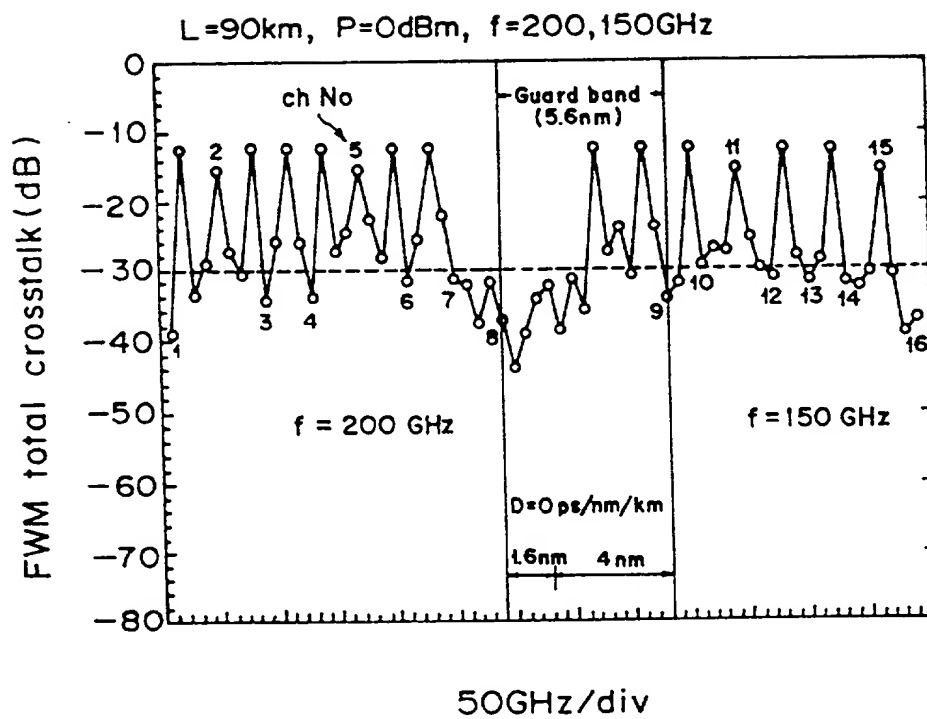


FIG. 8

CHANNEL SPACING $\Delta f = A \cdot X$ (A, B, C: INTEGERS
X: CONSTANT)
 $\Delta f' = B \cdot X$
 $\Delta f'' = C \cdot X$

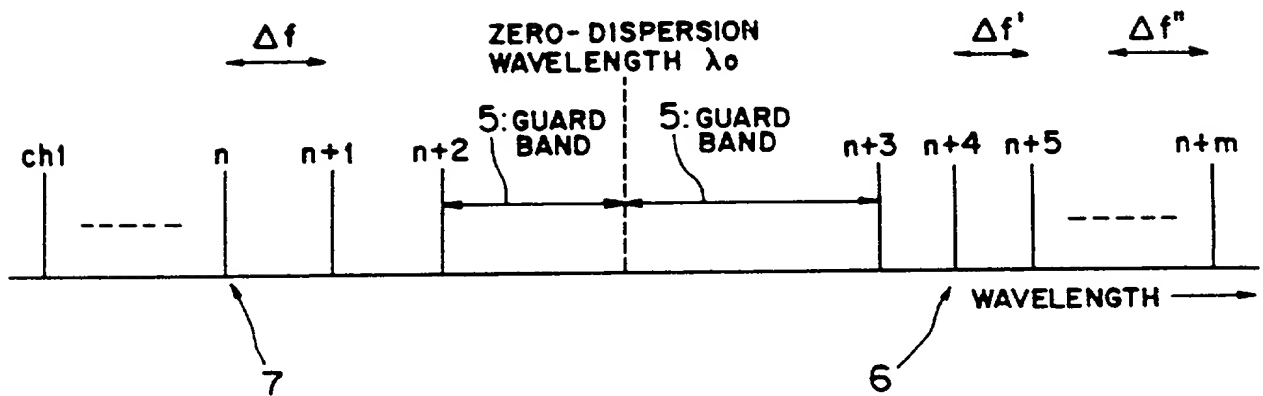


FIG. 9

WHERE OPTICAL FREQUENCY OF $ch_i = f$, SIGNAL LIGHT
WAVES ARE SET SO AS TO SATISFY OPTICAL FREQUENCY
OF $ch_j = f \pm A \cdot X$ (A: INTEGER, X: CONSTANT)

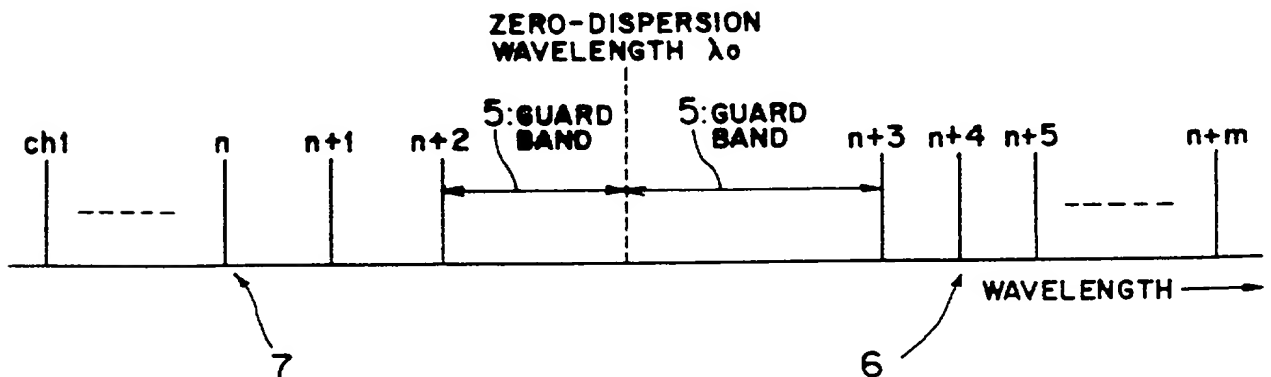


FIG. 10

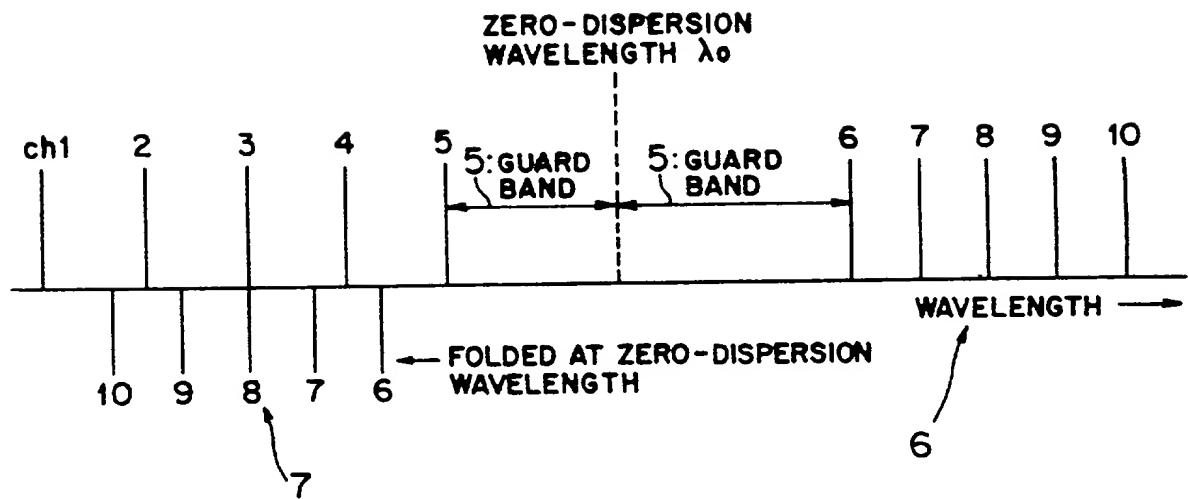


FIG. 11

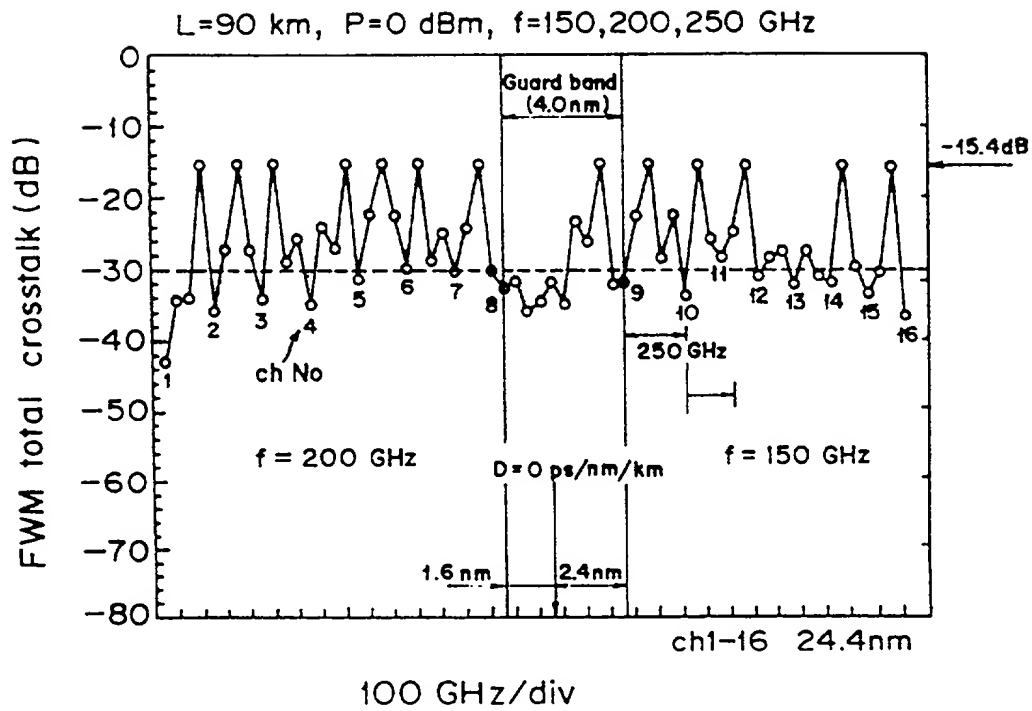


FIG. 12

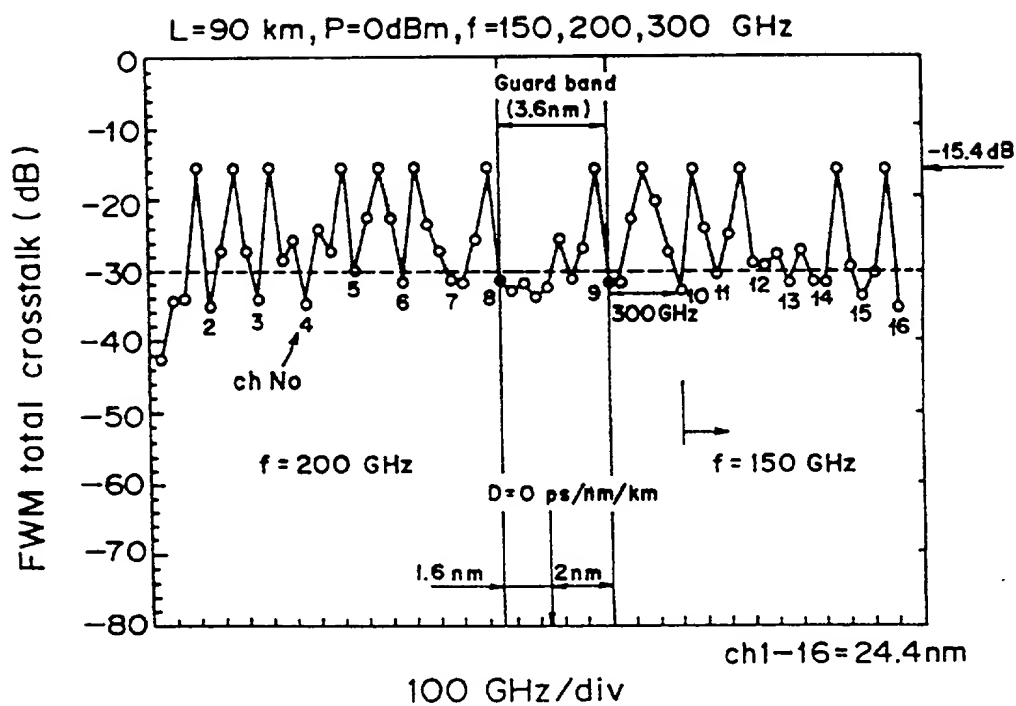


FIG. 13

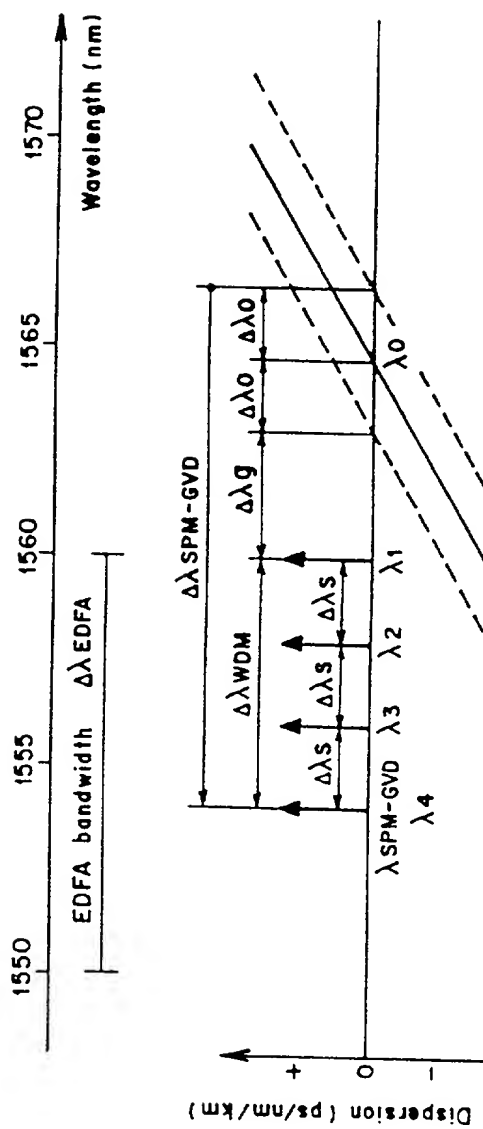


FIG. 15

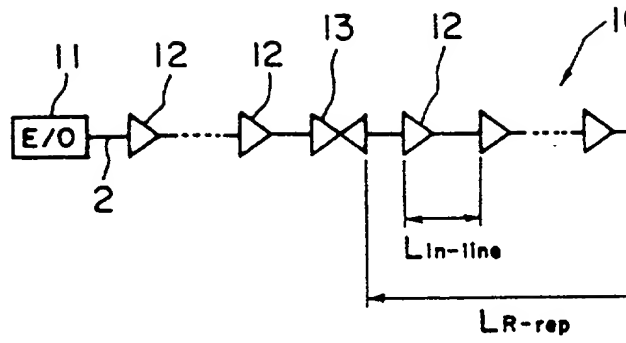


FIG. 16

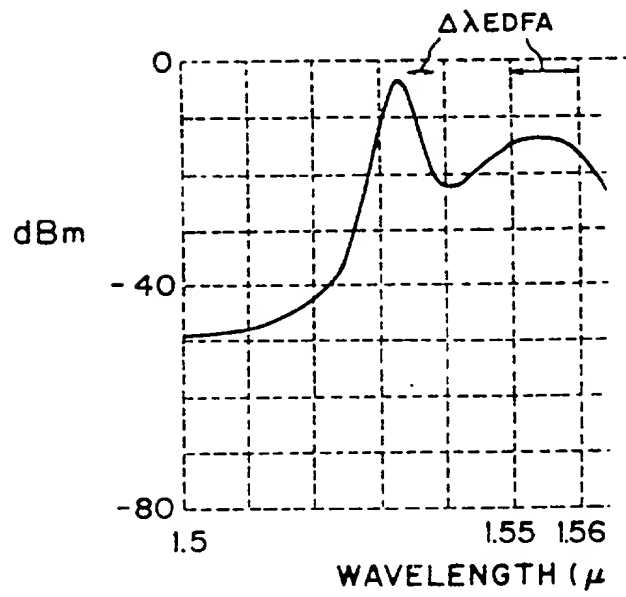


FIG. 17

ZERO-DISPERSION
WAVELENGTH OF OPTICAL FIBER

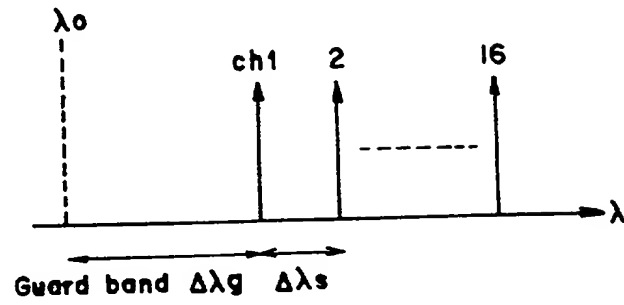


FIG. 18

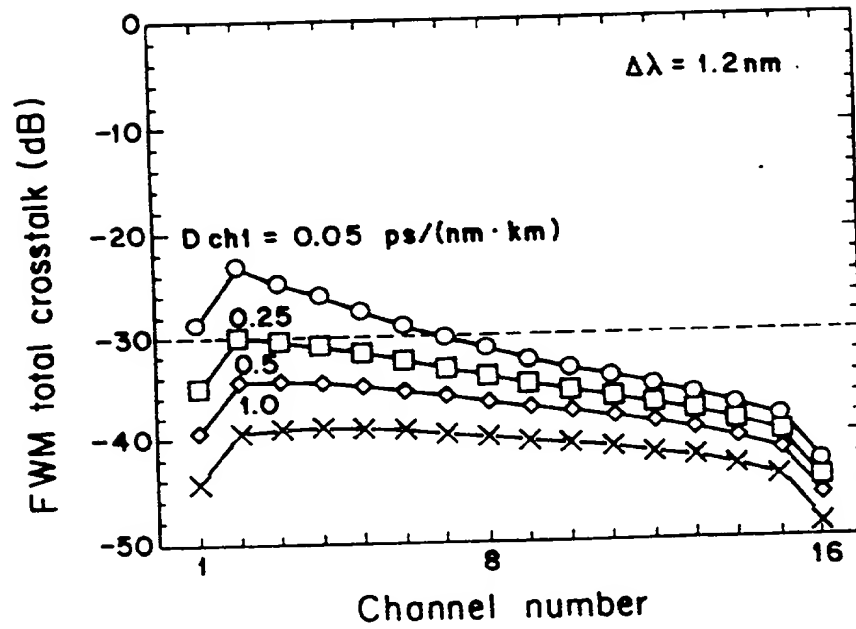
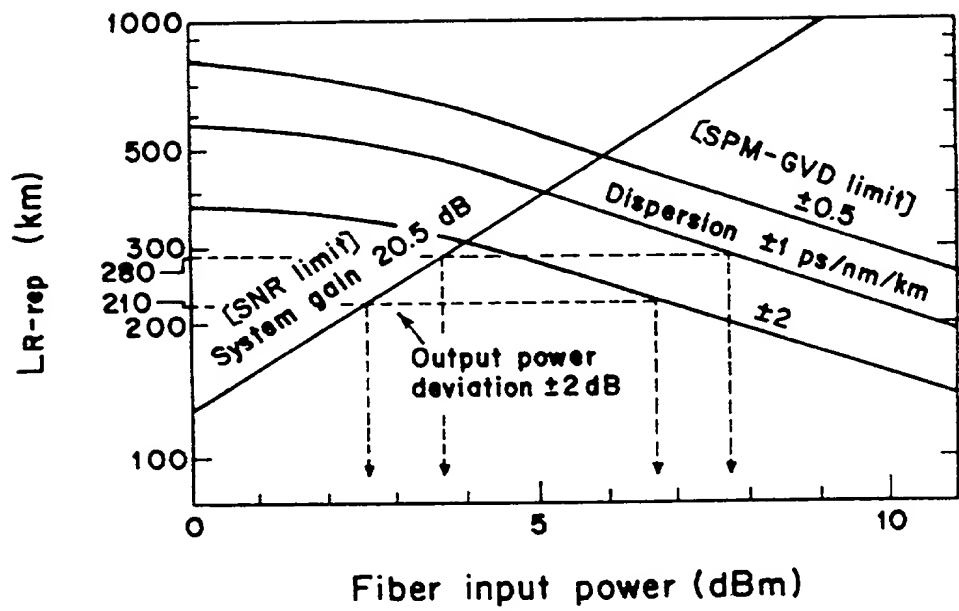


FIG. 19



10 Gb/s
 $L_{in-line} = 70$ km
 Pre-chirping $\alpha = \pm 1$
 NF = 8 dB

FIG. 20

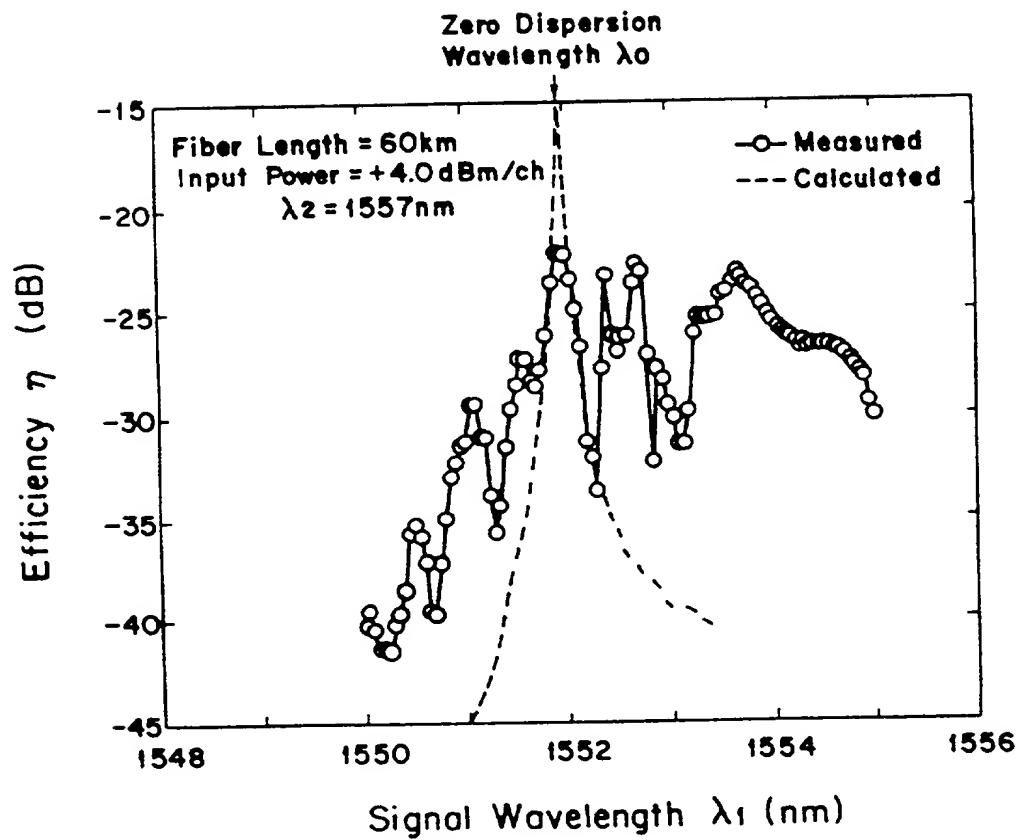


FIG. 21

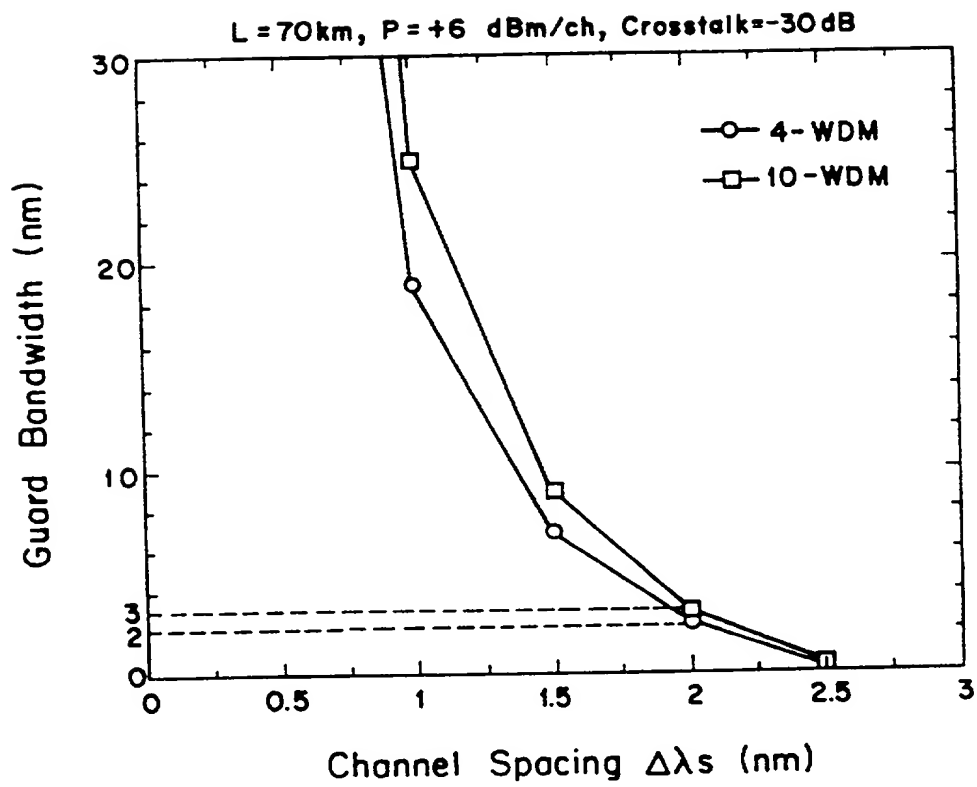


FIG. 22

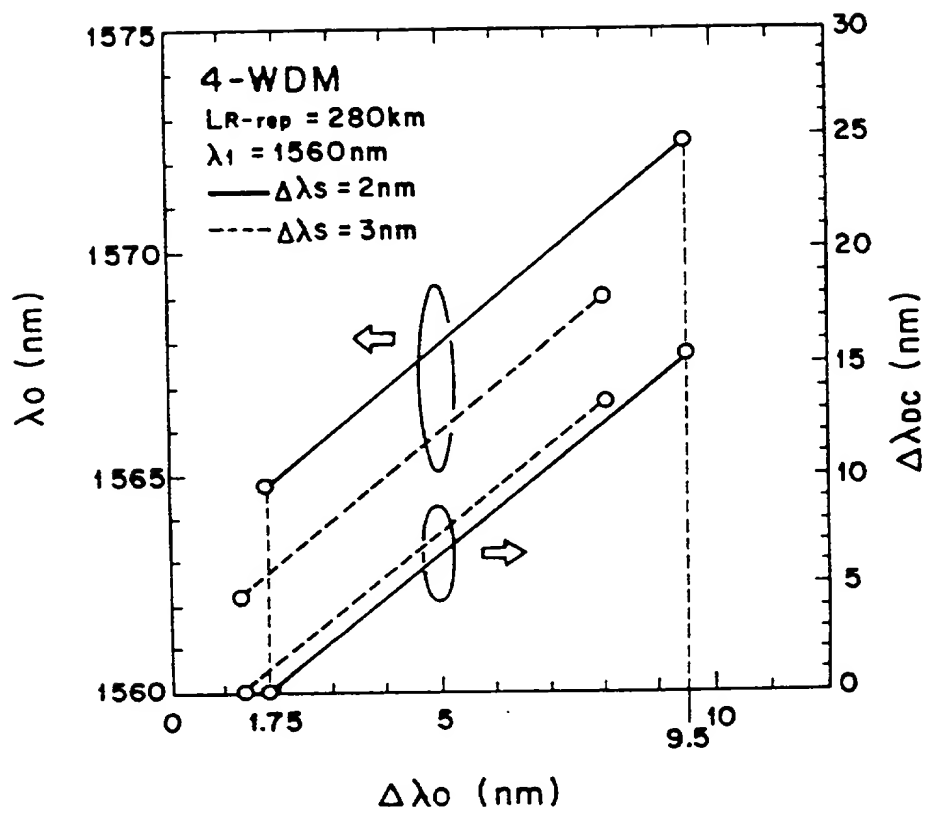


FIG. 23

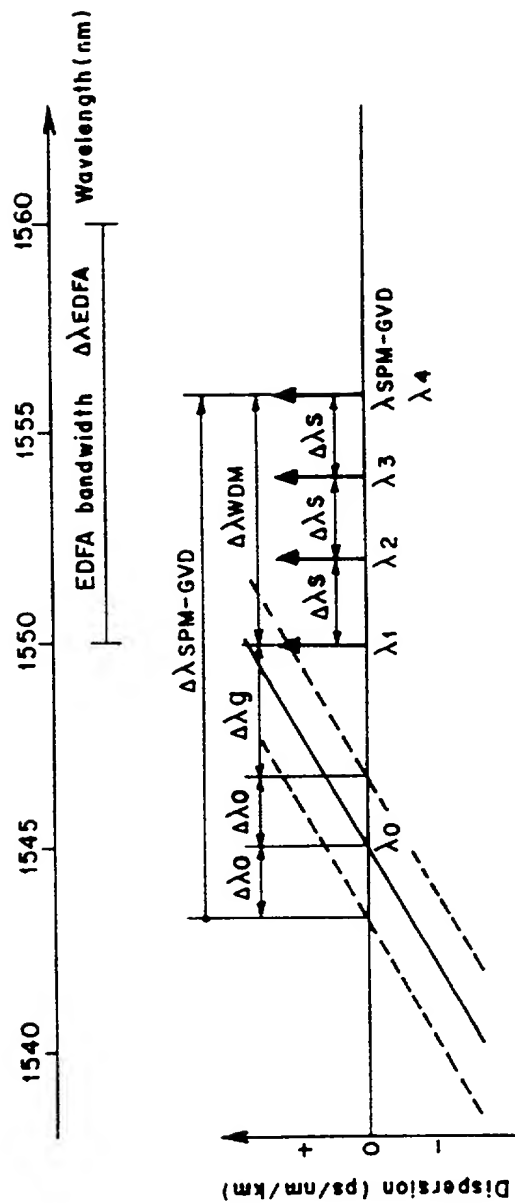


FIG. 25

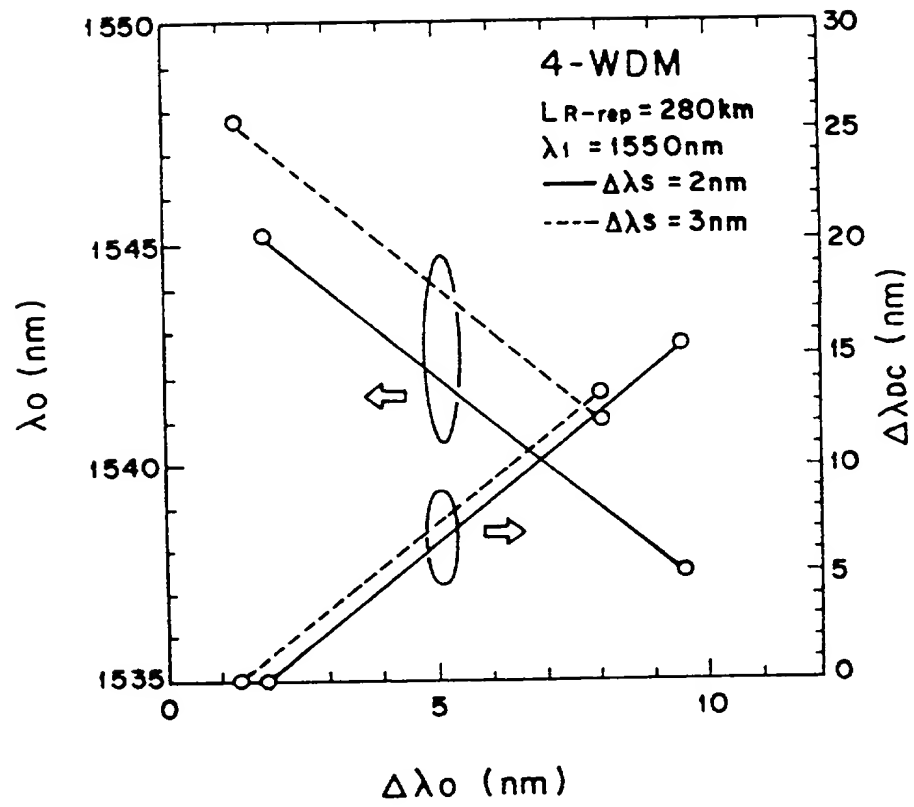


FIG. 26

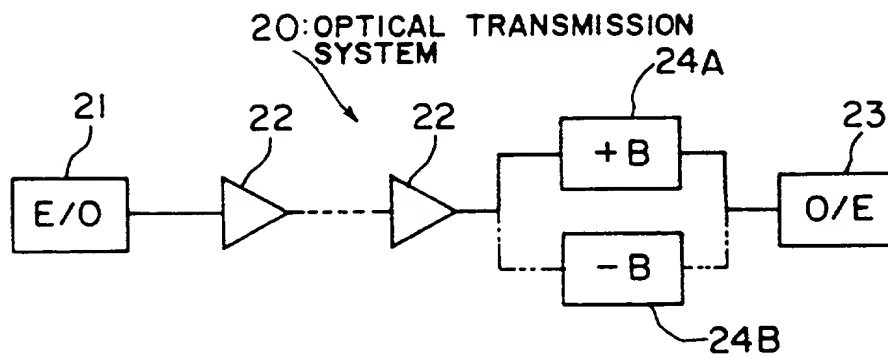


FIG. 27

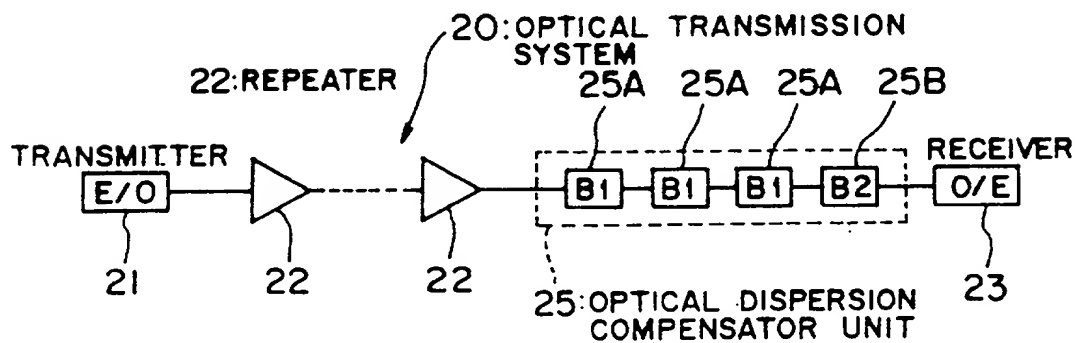


FIG. 28

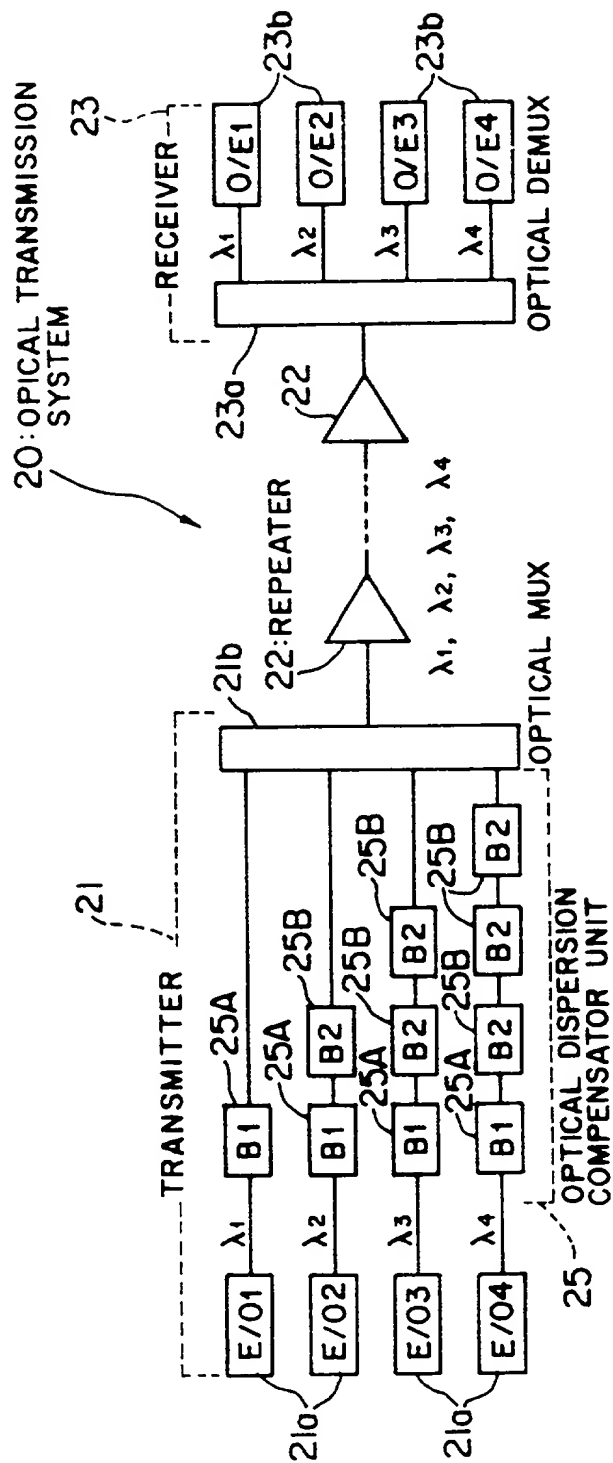


FIG. 29

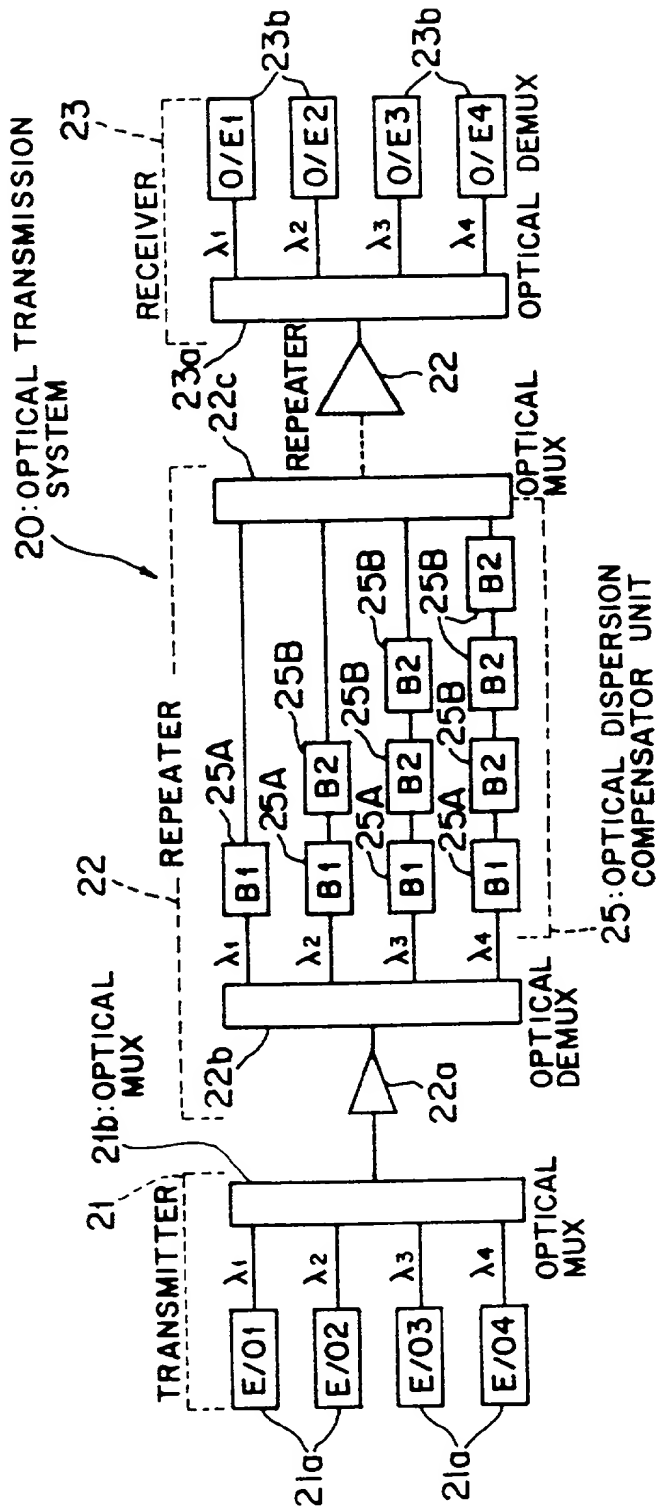


FIG. 30

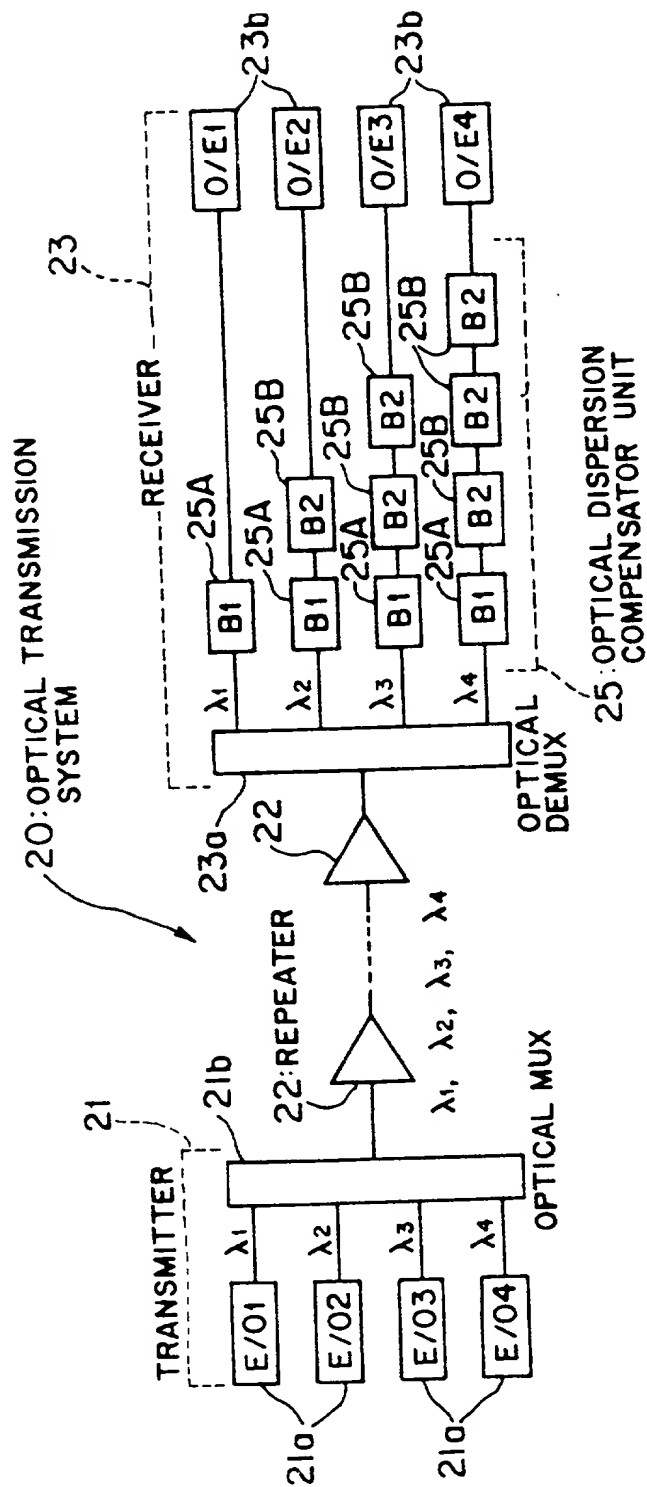


FIG. 31

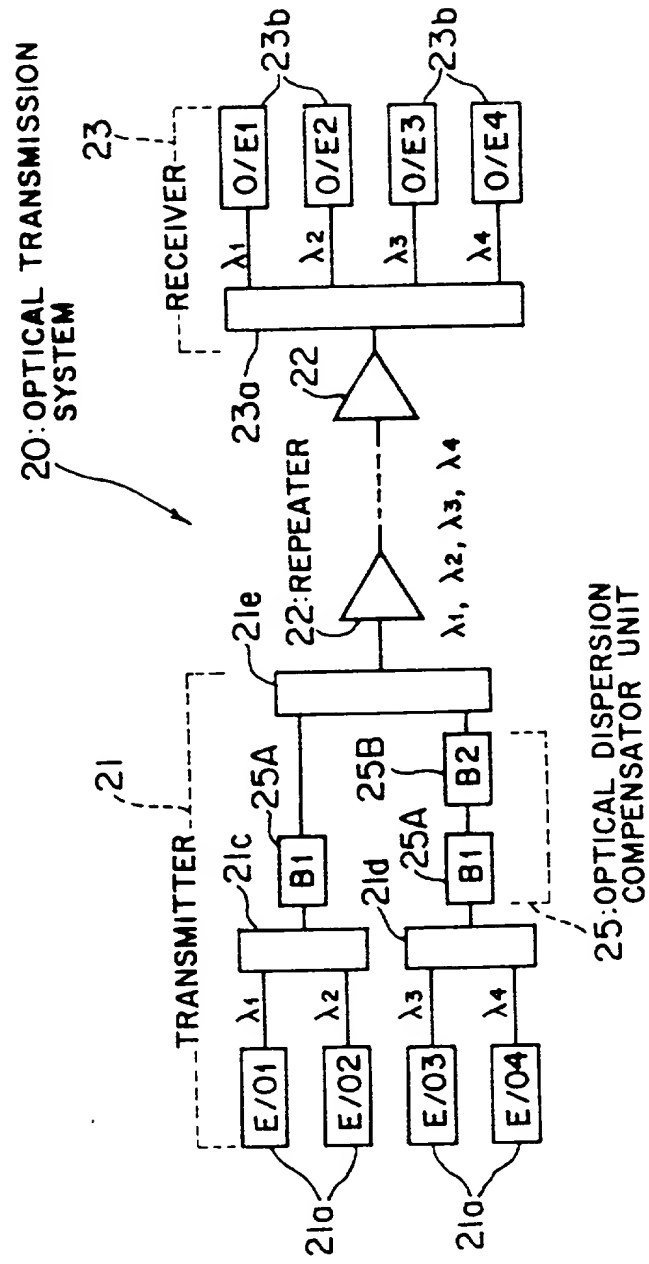


FIG. 32

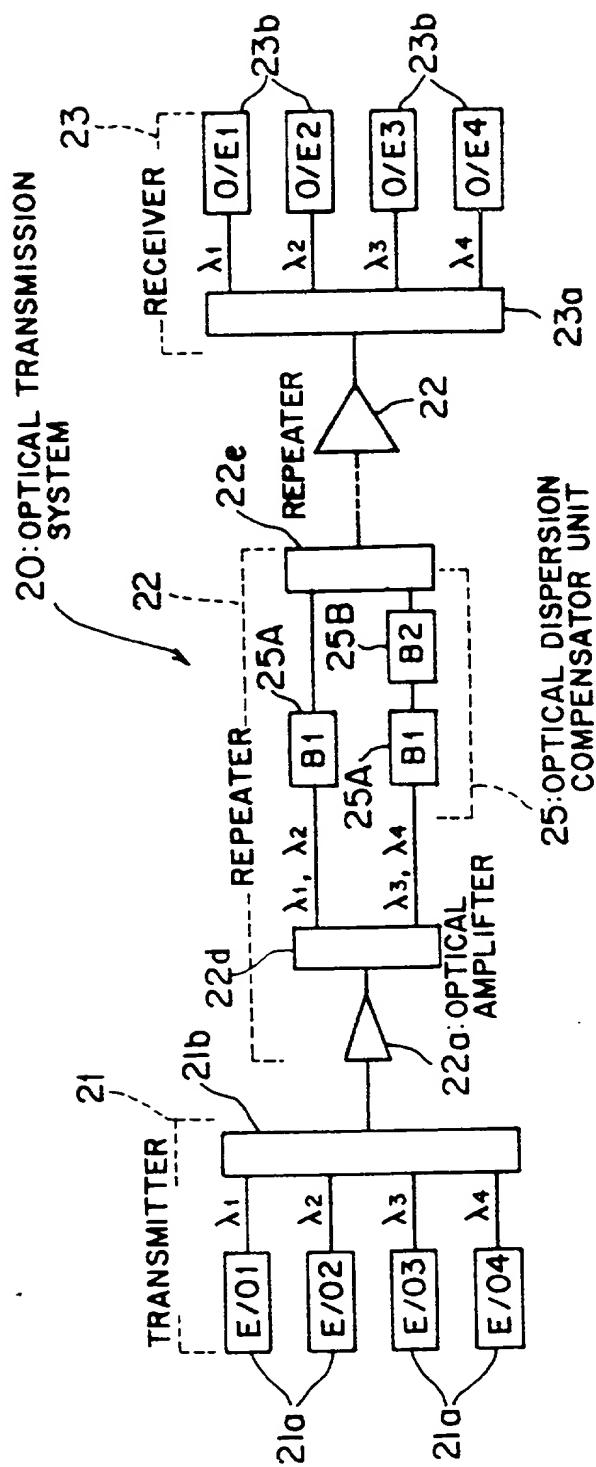
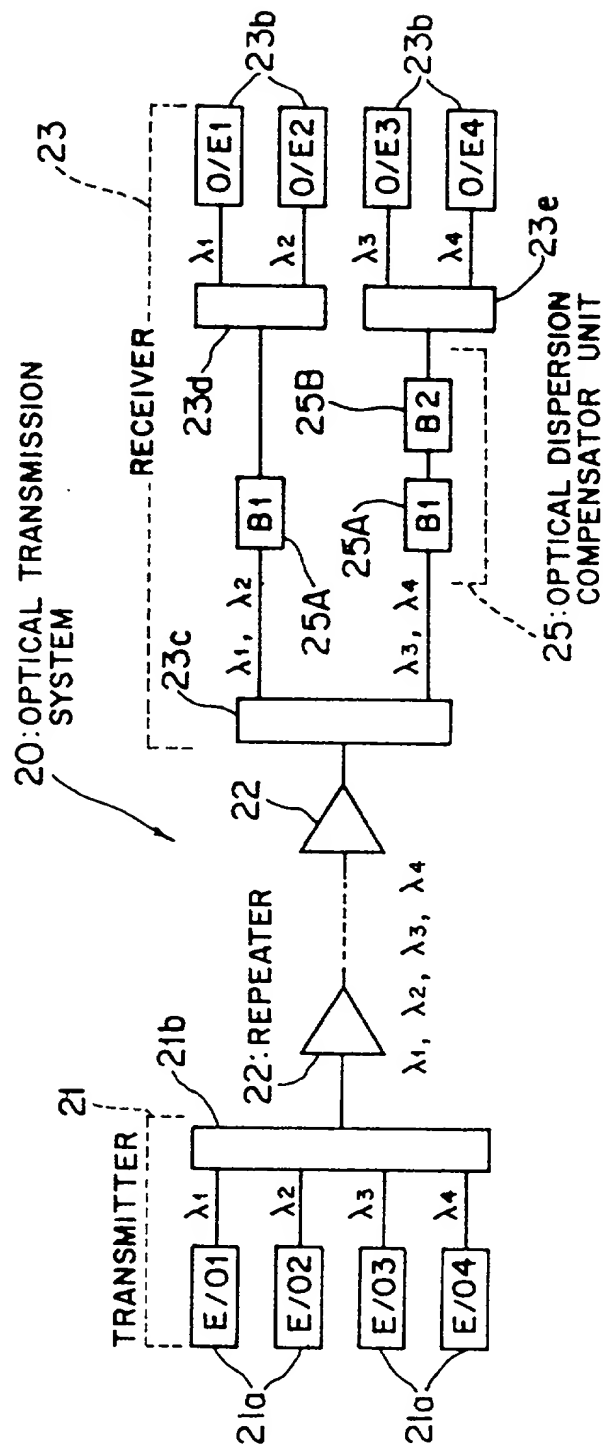


FIG. 33



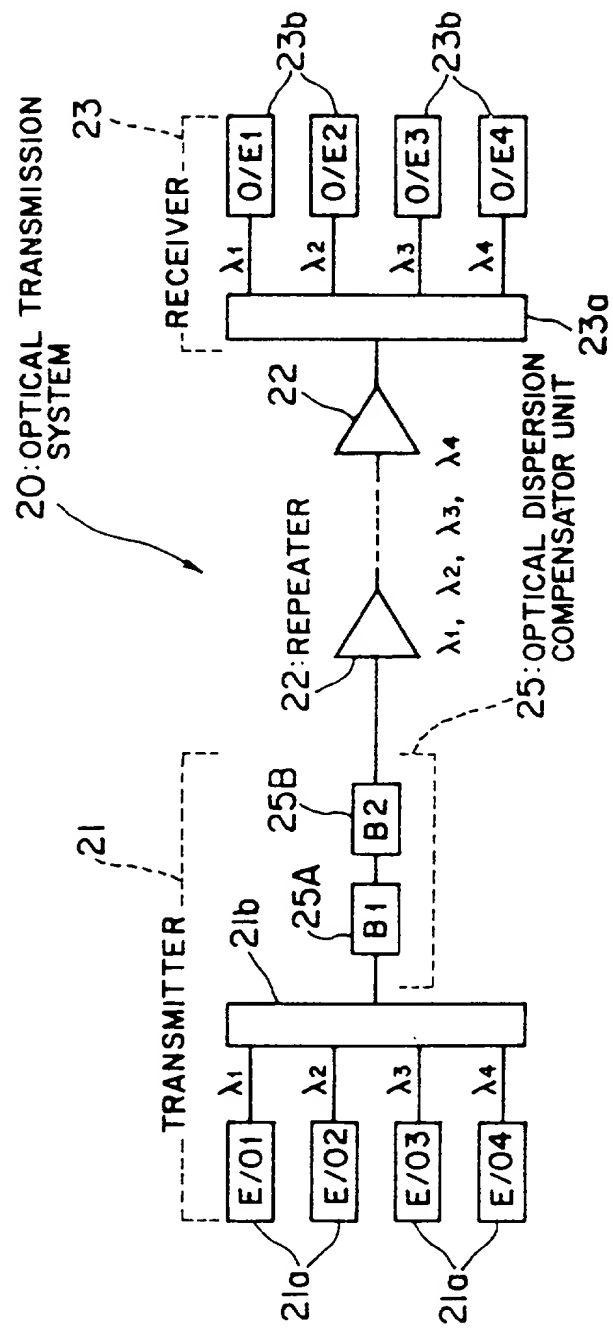


FIG. 34

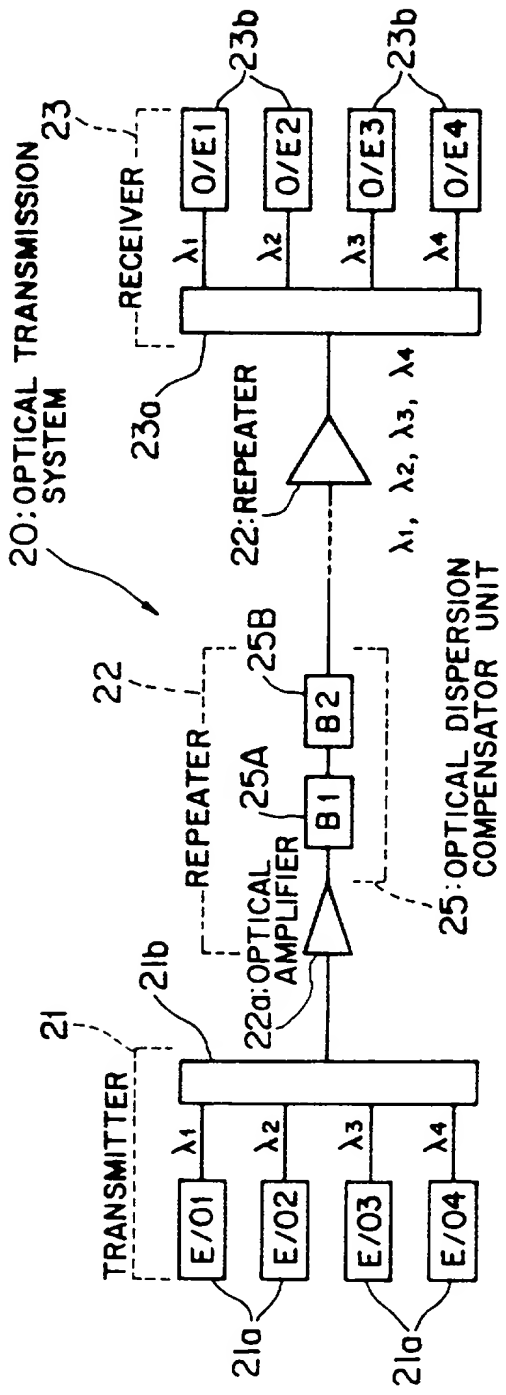


FIG. 35

FIG. 36

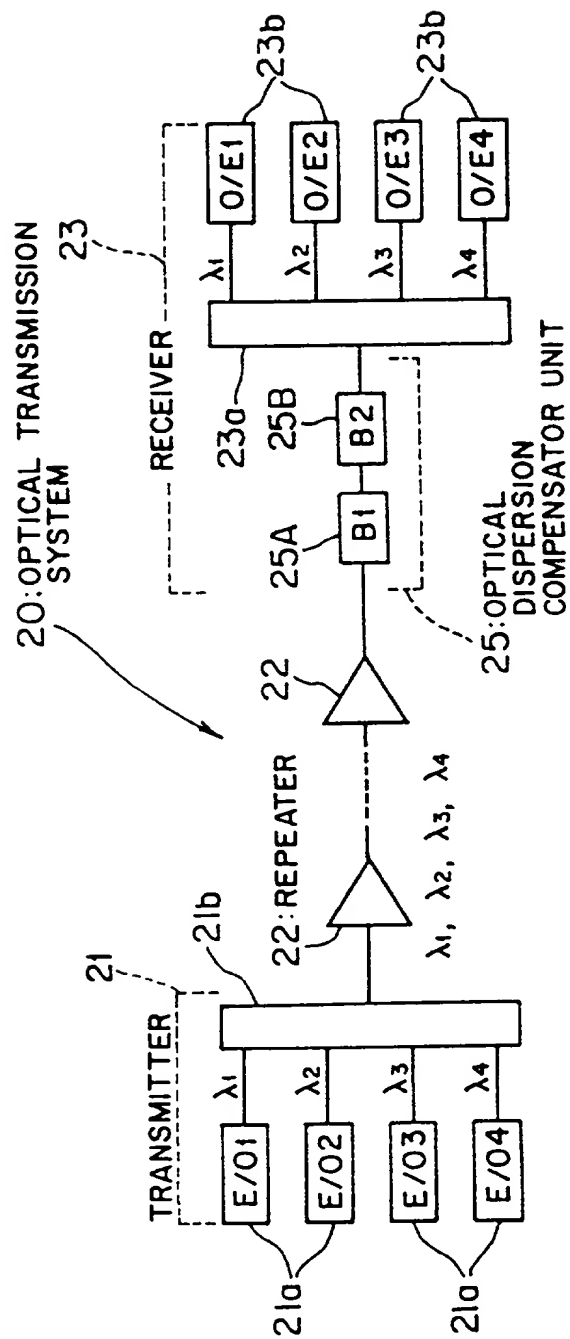


FIG. 37

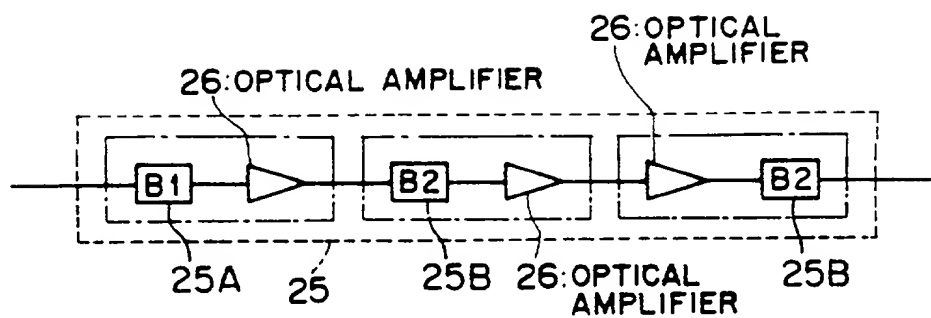


FIG. 38 (a)

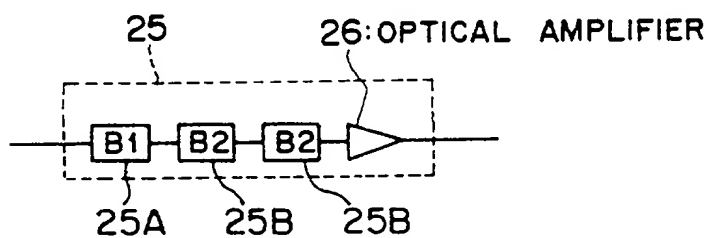


FIG. 38(b)

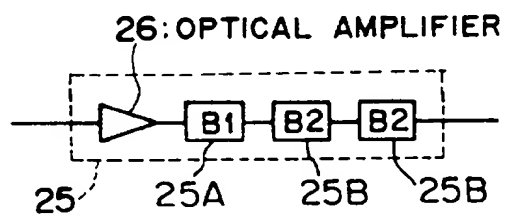


FIG. 39

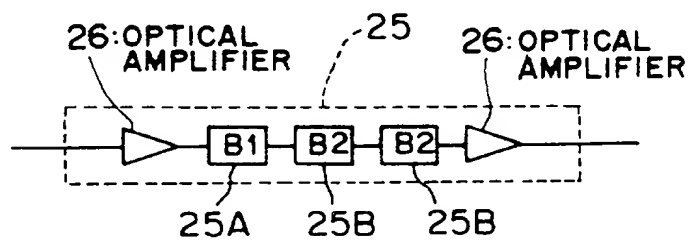


FIG. 40

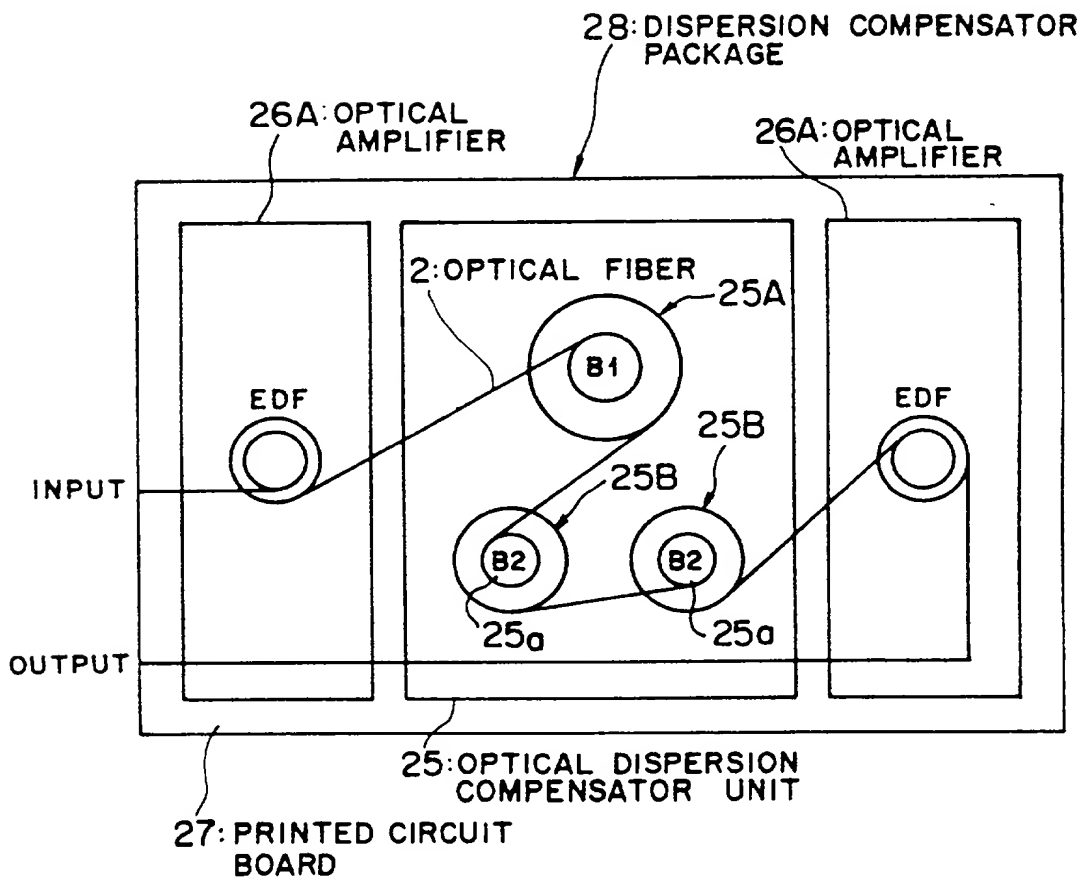


FIG. 41

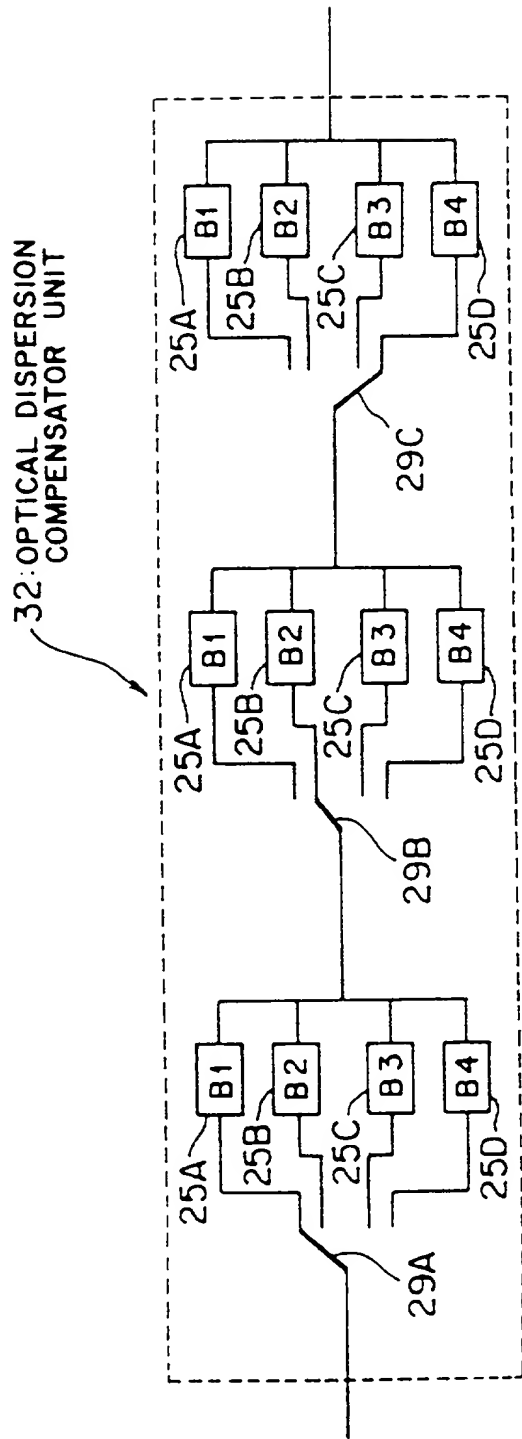


FIG. 42

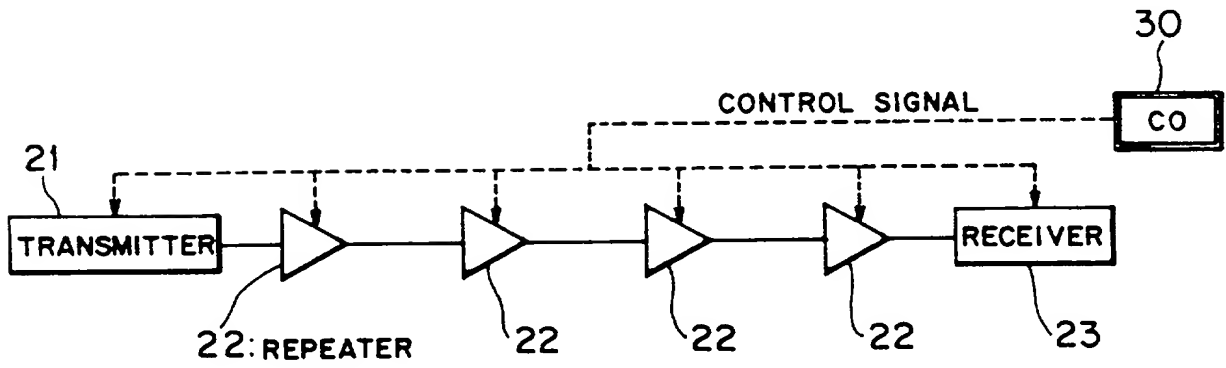
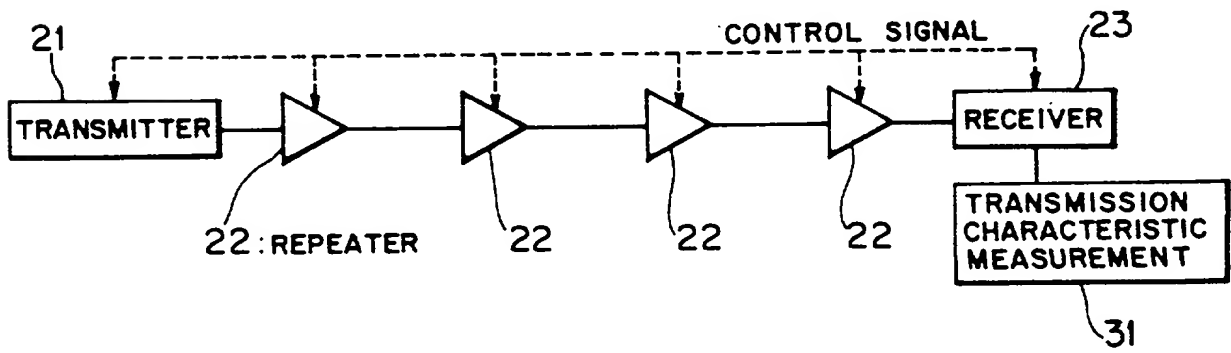


FIG. 43



COMBINED DECLARATION/POWER OF ATTORNEY FOR UTILITY/DESIGN PATENT APPLICATION

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name. I believe that I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled OPTICAL WAVELENGTH MULTIPLEX TRANSMISSION METHOD AND OPTICAL DISPERSION COMPENSATION METHOD

the specification of which (check one) ☒ is attached hereto ☐ was filed on _____
as U.S. Application Serial No. _____ and was amended on _____

(if applicable)

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above. I acknowledge the duty to disclose to the Office all information known to me to be material to patentability as defined in §1.56. I hereby claim foreign priority benefit(s) under 35 U.S.C. §119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application(s) for patent or inventor's certificate having a filing date before that of the application on which priority is claimed.

Patent Applications

Prior Foreign Application(s)

Priority Claimed

No. HEI 5-198674 (Number)	Japan (Country)	10/8/1993 Day/Month/Year Filed	(X) Yes	() No
No. HEI 5-242564 (Number)	Japan (Country)	29/9/1993 Day/Month/Year Filed	(X) Yes	() No

I hereby claim the benefit under 35 U.S.C. §120 of any U.S. application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application(s) in the manner provided by the first paragraph of 35 U.S.C. §112, and I acknowledge the duty to disclose to the Office all information known to me to be material to patentability as defined in §1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

(Application Serial No.) (Filing Date) (Status: patented, pending, abandoned)

(Application Serial No.) (Filing Date) (Status: patented, pending, abandoned)

POWER OF ATTORNEY:

As a named inventor, I hereby appoint the following attorneys and agent: James D. Halsey, Jr., Reg. No. 22,729; Harry John Staas, 22,010; David M. Pitcher, 25,908; Gene W. Stockman, 21,021; John C. Garvey, 28,607; J. Randall Beckers, 30,358; James M. Marsh, Jr., 24,533; William F. Herbert, 31,024; Richard A. Golhofer, 31,106; Carla M. Krivak, 30,956; Matthew J. Bussan, 33,614; Daniel W. Jufferbruch, 33,122; Jon M. Jurgovan, 34,633; Scott D. Balderston, 35,436; Mark J. Henry, 36,162; and Paul F. Daebeler, 35,852 to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. Send correspondence to: STAAS & HALSEY, 1825 K Street, N.W., Suite 816, Washington, D.C., 20006, and direct telephone calls to: (202) 872-0123

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. §1001, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full name of sole or first inventor George ISHIKAWA

Inventor's Signature George Ishikawa Date April 12, 1994

Residence Kawasaki-shi, Kanagawa, Japan

Citizenship Japanese

Post Office Address c/o FUJITSU LIMITED 1015, Kamikodanaka, Nakahara-ku, Kawasaki-shi, Kanagawa 211, Japan

Full name of second joint inventor, if any Hideyuki MIYATA

Second Inventor's Signature Hideyuki Miyata Date April 12, 1994

Residence Kawasaki-shi, Kanagawa, Japan

Citizenship Japanese

Post Office Address c/o FUJITSU LIMITED 1015, Kamikodanaka, Nakahara-ku, Kawasaki-shi, Kanagawa 211, Japan

Supply similar information and signature lines for third and subsequent joint inventors.)

S & H 3/90
Page 2

UNITED STATES

Docket No. _____

COMBINED DECLARATION/POWER OF ATTORNEY FOR UTILITY/DESIGN PATENT APPLICATION

Full name of third joint inventor, if any Hiroshi ONAKA

Inventor's Signature Hiroshi Onaka Date April 12, 1994

Residence Kawasaki-shi, Kanagawa, Japan

Citizenship Japanese

Post Office Address c/o FUJITSU LIMITED 1015, Kamikodanaka, Nakahara-ku, Kawasaki-shi, Kanagawa 211, Japan

Full name of fourth joint inventor, if any Motoyoshi SEKIYA

Inventor's Signature Motoyoshi Sekiya Date April 12, 1994

Residence Kawasaki-shi, Kanagawa, Japan

Citizenship Japanese

Post Office Address c/o FUJITSU LIMITED 1015, Kamikodanaka, Nakahara-ku, Kawasaki-shi, Kanagawa 211, Japan

Full name of fifth joint inventor, if any Kazuo OTSUKA

Inventor's Signature Kazuo Otsuka Date April 12, 1994

Residence Kawasaki-shi, Kanagawa, Japan

Citizenship Japanese

Post Office Address c/o FUJITSU LIMITED 1015, Kamikodanaka, Nakahara-ku, Kawasaki-shi, Kanagawa 211, Japan

Full name of sixth joint inventor, if any _____

Inventor's Signature _____ Date _____

Residence _____

Citizenship _____

Post Office Address _____

Full name of seventh joint inventor, if any _____

Inventor's Signature _____ Date _____

Residence _____

Citizenship _____

Post Office Address _____